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THE MANCHESTER

STEAM USERS' ASSOCIATION.

ESTABLISHED 1854.

MEMORANDUM BY CHIEF ENGINEER, FOR THE YEAR 1905.

MANCHESTER:
TAYLOR, GARNETT, EVANS, AND CO., LTD., BLACKFRIARS STREET; ALSO AT REDDISH AND LONDON.
1906.

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MANCHESTER STEAM USERS' ASSOCIATION.

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MEMORANDUM BY CHIEF ENGINEER.

May 22nd, 1906.

TO THE EXECUTIVE COMMITTEE.

GENTLEMEN,

Much time and space were devoted in last year's Memorandum to the Jubilee Celebrations, so that it was not deemed desirable to deal fully with other matters of general interest.

SPECIFIC HEAT OF SUPERHEATED STEAM.

Foremost amongst those left over should be the experiments which were initiated by this Association, and which are being carried out by the National Physical Laboratory on the specific heat of superheated steam. They are, it appears, progressing favourably, but are not yet completed. How great are the difficulties which have had to be surmounted will be evident from a comparison of the results of other experimenters, for according to some the specific heat of steam increases with rising pressures and temperatures, whereas according to others it is either a constant value or decrease. In one set of experiments superheated steam is mixed with air of which the specific heat is known; in another set of experiments superheating is produced by wiredrawing the steam and comparing the original and final temperatures and pressures; and in the experiments now being carried out by the National Physical Laboratory the superheating of the steam is done by electrically-heated wires, and the heat thus supplied is then compared with the increase of temperature. With each method there is danger of systematic errors being introduced; but these, it is believed, have now been avoided or can be accounted for.

STEAM PRESSURE GAUGES.

At the suggestion of this Association, the National Physical Laboratory has inquired into the best possible performance of first-class steam-pressure gauges, and a preliminary report has been issued, of which the following is a copy :—

TESTS ON PRESSURE GAUGES. DR. STANTON AND MR. BAIRSTOW.

The proposed tests on pressure gauges suggested in the Report for 1904 have been carried out, and a full report of the tests communicated to the Director. Ten gauges were submitted for testing purposes by the makers, and were subjected to tests to determine the effect of friction, backlash, temperature, and vibration, together with endurance tests.

The vibration tests were made at three different periods and amplitudes of vibration. Of the gauges tested one was balanced and the remaining nine unbalanced. The vibration tests showed that considerable disturbance of the gauge pointer was produced in the case of all the unbalanced gauges, and that the balanced gauge was practically unaffected in all cases. The results of the other tests indicated that all the gauges were of exceptionally high quality.

The object of this inquiry was to ascertain whether it would be possible to fix on standards of excellence for pressure gauges for different kinds of duties. Bad workmanship, entailing either excessive friction or backlash, is an objectionable feature which is easily detected; but, as has been shown by Mr. Whimper's experiences in the Andes, aneroid barometers, and therefore pressure gauges also, may lose their elasticity if pressed for a long time. Few if any materials are as free from elastic fatigue as quartz has been found to be. Steel and some bronzes also seem to be very good in this respect, but some bronze or brass tubes are exceedingly unreliable in their indications. Then again, the elasticity of some metals, except, as far as is known, quartz and invar, and iron nickel alloy, are seriously affected by changes of temperature, and a knowledge of the best possible results obtainable should be of advantage. Reference is also made to the possibility of entirely preventing the vibrations of gauge pointers, which is such an objectionable feature with all gauges attached to fast-running engines.

Steam-pipe Explosions.

The recent lamentable accident to the steam pipe of a new installation at Messrs. Bright's Mill, Rochdale, has once more drawn attention to the dangerous design of many steam-pipe installations, and of late several requests have been received from members to report on their steam pipes. Little can be added to what was said on this subject in my Memorandum of 1901, except that all steam-pipe explosions which have occurred since then have been due to the causes then pointed out, and could, of course, have been prevented by inspection. A glass tube apparatus was devised at the time, which was shown at soirées of the Royal Society and of the Civil Engineers, and was described to several other scientific societies. It is illustrated in Fig. 1.

F is a glass flask of about 1 quart capacity placed over a Bunsen gas burner B; its stopper is provided with a Bunsen safety valve *b*, which is merely a short piece of india-rubber tubing closed at one end and slit for about $\frac{1}{2}$in. along its middle. There is a steam-pipe connection to the L-shaped glass tube of about $\frac{3}{4}$in. bore marked T T T. The vertical leg is about 1ft. high, and the horizontal leg is about 18in. to 24in. long. A small glass tube with a pinchcock P_1 is fitted at the bend, and another pinchcock P_2 is fitted at the other end. They had both best be connected to a fair length of tubing reaching into a water reservoir from which the tube T T T can be filled up to the water level W L.

Pressure is raised in F, and when steam is blowing off freely at *b* the pincheock P_1 or P_2 is opened, and the water level depressed below the top level of the lower leg. The condensation of steam which now takes place over a considerable water surface raises a wave near the bend, and as the imprisoned steam is still being condensed, a vacuum bubble is formed which naturally at once collapses with a sharp blow. The connecting pipes, being of india-rubber, prevent the glass tube from being shattered, but it has frequently happened that the plug at P_2 has been blown out.

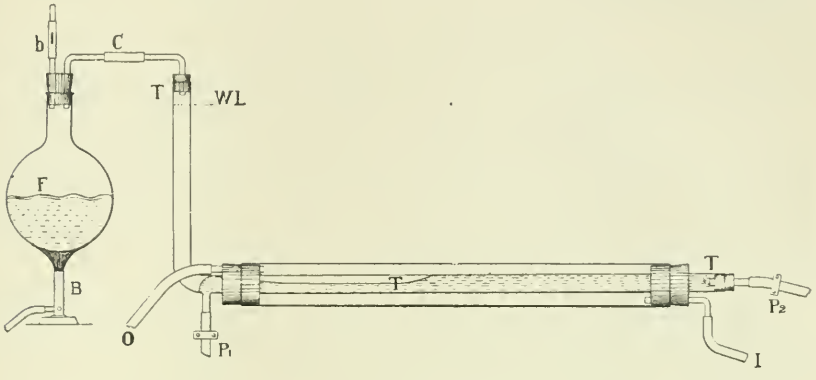


Fig 1

The first blow is followed by a few feeble ones, and the hammering ceases, due to the water in the lower leg having grown hot. For purposes of demonstration, it is therefore best to surround the lower leg with a glass jacket as shown, through which water circulates, then the phenomena of formation of waves, &c., can be very thoroughly watched over lengthened periods.

In this apparatus the pipe T T T represents a steam-pipe connection from the junction valve of the closed boiler, which is supposed to be at P_2, to the main steam pipe, which is at C. The steam from the flask represents the steam which the other boilers are supplying.

Experiments carried out with such an apparatus have demonstrated that very severe water-hammer blows can occur, even when the P_2 end is lower than the P_1 end. This was confirmed quite recently by the bursting at the centre of its length of a very long slanting steam pipe. It had been out of use for some time, and doubtless was full of water. Steam was turned on, and the draincock at the lower end opened, when suddenly the pipe burst near the middle of its length. There was nobody near at the time, so that it is uncertain whether there were any preliminary water blows. There was nothing defective in the pipe, which was considerably bulged near the rent, indicating that the metal was not bad but that the concussion must have been a very serious one.

Steam pipes and their valves are by Act of Parliament defined as being boilers, and whenever they explode notice should be sent to the Board of Trade, when, of course, an official inquiry will be ordered. For this reason, and because of the general danger, the attention of our members is drawn to any pipe arrangements which our inspectors should chance to see and find dangerous; but as steam pipes are not covered by the guarantee on the boiler, it is, of course, impossible to devote to them the detailed attention which they deserve; but any request from members to have their steam-pipe range examined and reported on would, of course, receive prompt attention.

Brittleness of Mild Steel.

During the past year or two the confidence placed by the engineering world in mild steel has been shaken by a few failures, for which as yet no satisfactory explanations have been found; but inquiries have been set on foot, of which it is hoped that if they do not throw any light on the true cause, they may at least point to some test which will discover the doubtful material before it gets into the hands of the boiler maker.

Some interesting cases were dealt with in a report by Prof. Arnold, read before the Institution of Naval Architects, and several similar ones have recently come under my immediate notice.

When, at the end of the seventies, mild qualities of steel were first made in the open-hearth furnace, it was hoped that a more reliable substitute had been found for iron than Bessemer steel could claim to be; and after a short experience, especially on war vessels, the French and English Admiralties, followed by Lloyd's Register, fixed on certain quality tests which, so it was hoped, would discriminate between reliable and unreliable steel, or rather between open-hearth and converter steel. In those days the chief cause of unreliability was believed to be the unequal distribution of carbon in Bessemer steel, and the most effective conditions for excluding this steel were that the material should have a high tenacity, say 25 tons and upwards; a good elongation, say above 20 per cent., and the material should show no sign of brittleness after being heated to a bright-red heat and plunged into water of 28° C. or 82° Fah. By this means the use of the somewhat uncertain Bessemer steel was practically stopped for ship and boiler plates; but in spite of careful testing, iron never having been tested to the same extent, alarming failures were still experienced. The best-known of these was the breaking of the shell plates of the boilers intended for the Imperial Russian yacht "Livadia." It will be remembered that after some of her boilers had been built, one of them burst while being tested, and others were found to be fractured before testing, and these plates, which had stood the workshop practice, broke when being taken to pieces. The nature of the process by which the steel was made was not divulged, but that it led to irregular distribution of constituents was evident

from a series of analyses, of which one set was made on the different layers of one sample, $\frac{7}{8}$in. thick. The percentages were as follows :—

TABLE I.

No. of Layer.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
1	0·100	—	0·054	0·040	0·280
2	0·110	—	0·065	0·054	0·230
3	0·120	—	0·080	0·069	0·367
4	0·150	—	0·131	0·076	0·410
5	0·160	—	0·097	0·077	0·283
6	0·180	—	0·123	0·079	0·283
7	0·160	—	0·066	0·072	0·348
8	0·190	—	0·105	0·074	0·381
9	0·200	—	0·177	0·095	0·371
10	0·180	—	0·118	0·086	0·237
11	0·180	—	0·098	0·079	0·288
12	0·160	—	0·090	0·076	0·237
13	0·110	—	0·052	0·050	0·360
14	0·090	—	0·018	0·039	0·381
Mean	0·149	—	0·091	0·069	0·318
Another sample					
1	Trace	—	—	—	—
2	0·050	—	—	—	—
3	0·070	—	—	—	—
4	0·100	—	—	—	—
Mean	0·055	—	—	—	—

The carbon ranged from 0·09 to 0·20 ;
The sulphur from 0·018 to 0·123 ;
The phosphorus from 0·039 to 0·079 ;
And the manganese from 0·230 to 0·410.

In the other sample, whose fracture showed very marked segregations, the carbon varied from " a trace " on one side to 0·050, 0·070, and 0·100 on the other side. In addition, 11 analyses were made of different parts of the plates, the results being as follows :—

TABLE II.

	Carbon.	Silicon.	Sulphur.	Phosphorus	Manganese.
Maxima and Minima of 11 Samples	0·127 to 0·063	0·063 to trace	0·094 to 0·064	0·064 to 0·045	0·640 to 0·42
Mean of 14 Layers ..... See previous	0·149	—	0·091	0·069	0·318
Fractured Sample, Mean	0·055	—	—	—	—

The tensile tests of the fractured plates varied from 29¼ tons to 34¼ tons tenacity, and elongations of from 11¼ per cent. to 23·9 in 8in., except that some samples cut out between the punched rivet holes were quite brittle.

Shortly after this failure Mr. Maginnis published in "The Engineer," December, 1885, Vol. 60, pp. 447, &c., details about the failure of some other marine boilers which had been at work for $2\frac{1}{2}$ years. He says :—

(1) The material used for two different sets of boilers, each set consisting of three circular boilers with horizontal steam chests, passed all tests required by the Board of Trade and Lloyd's. (2) The material stood without the slightest defect the ordinary work of the boiler shop, including welding, &c. (3) Each set of boilers worked satisfactorily at sea for a period of $2\frac{1}{2}$ years, after which they then exhibited signs that a complete change had taken place in the nature of the steel.

Apparently the boiler plates had become absolutely brittle. The tenacities of the original plates varied from $26\frac{1}{4}$ to $30\frac{1}{4}$ tons, with elongations of from $19\frac{3}{4}$ to 27 per cent. The tensile tests of plates cut from the fractured combustion chambers, of which only two original tests are included in the above, showed tenacities of 25, 26, and 45 tons, with elongations up to 27 per cent. for the first two, and up to 15 per cent. for the hard plate.

The chemical analysis of the cracked combustion chamber plates were as follows :—

TABLE III.

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
0·125	0·005	0·051	0·060	0·320
0·175	0·018	0·045	0·008	0·370
0·125	0·018	0·043	0·061	0·530

The steel had been made by the Bessemer process, which cannot, like the open-hearth process, be relied upon to produce material of exactly the composition aimed at. Apparently, a few hard plates had not been detected by the mechanical tests at the steel works, but all showed themselves to be sufficiently ductile during construction to withstand the rough usage in the boiler shop, some at least grew perfectly brittle during the subsequent long period.

When about the time of these failures I discovered that mild steel could be made permanently brittle by merely heating it to a temperature of melting lead and bending or hammering it, hopes were entertained that similar failures could now be explained, but there are evidently other causes than working steel at a blue heat which will produce brittleness, and one which was very early recognised was the presence of phosphorus in the steel in excess of, say, 0·07 per cent.

A notable case of three ships being built of this quality of steel soon drew renewed attention to the danger of using it. Two of these ships were launched and went to sea; but fractures of their beams and angle irons were so frequent that an inquiry was made into the condition of the third ship which was still on the stocks. It was found that nearly every frame and beam could be broken by heavy blows of a hammer

and that, too, in spite of the fact that these parts had shown no signs of brittleness when new, lending themselves to bending, punching, drilling, hammering, and riveting operations without either breaking or cracking. This steel had been made by the basic Bessemer converter, which once more showed that it could not be depended upon to turn out reliable material. If it were brittle immediately after rolling and shearing, such material would be thrown out before leaving the steel works, but the chief danger has to be sought for in what I believe to be a fact—that this, and perhaps other, classes of steel possess the objectionable quality of deteriorating during periods of rest.

It is well known that elastic sulphur will after a time change into a brittle crystalline form, and in Sheffield the opinion is almost universally held that their steel improves by years of keeping. Why should not other qualities change and perhaps deteriorate? At anyrate, my subsequent experiences have tended strongly to confirm this view, and quite recently the following case revived the question.

Brittleness Due to Phosphorus.

One of a set of steel plates which had all satisfactorily withstood the tensile temper and cold bending tests cracked in two places while being slowly bent to the curvature of the shell of which it was to form part. The test samples had been bent to a radius of, say, 1¼in. without fracture, but two weeks later the same material cracked when bent to a radius of about 20ft. to 30ft. The material was analysed with the following result :—

TABLE IV.

Carbon	0·150 per cent.
Silicon	0·011 „
Sulphur	0·032 „
Phosphorus	0·162 „
Manganese	0·540 „
Copper	—
Arsenic	0·023 „

It will be seen that the phosphorus is very high, and it was discovered that this was due to a load of phosphoric pig having been charged into the acid furnace instead of the basic one. Of course, in the acid furnace no reduction of phosphorus takes place. The mechanical tests which were carried out with this steel after failure revealed nothing abnormal in its condition, but a microscopic examination gave indications that an excess of phosphorus was present; but it is yet too early to depend on what is seen in the microscope, for this very steel, although its sulphur is low, contains a comparatively large number of dove-coloured patches, which are generally supposed to consist of sulphide of manganese. The view at present held about phosphorus in steel is that it can exist in two allotropic forms, of which one is harmless, the other brittle. Possibly a change of condition, which may be produced by time alone, produces the changes of quality which have led to these remarks.

Heat Treatment of Steel.

Another cause of brittleness is believed to be improper heat treatment. The general opinion is, that this brittleness can be removed by renewed judicious heating, especially if accompanied by hammering or rolling, from which it would follow that the last heating process to which a piece of steel is subjected would have an all-important effect. Others seem to hold that every heat treatment through which a piece of steel passes leaves its mark. According to this view the temperature at which a charge is cast should influence its qualities. This is in a measure confirmed by differences of tenacity of steels of the same chemical composition, but made at different works, and also by the great difference of quality between the purest wrought iron and the purest steels. The former material has never been heated above a welding temperature, the latter has been in a molten condition. If this view is correct then even the temperature of the furnace used for reheating before rolling should affect the quality of the finished article. This may have been the cause of a recent failure of another plate.

Like the previously-mentioned one, it had been satisfactorily tested at the steel works, and being intended for butt straps it was being sheared again at the boiler works, when, to the surprise of everybody these strips broke and fell off in bits.

All the plates from the same cast were at once rejected, but no tests to which they were then subjected, nor yet the chemical analysis, which was as under, revealed anything wrong, for both the phosphorus and the sulphur are low :—

TABLE V.

Carbon	0·175 per cent.
Silicon	0·011 ,,
Sulphur	0·030 ,,
Phosphorus	0·059 ,,
Manganese	0·560 ,,
Copper	0·069 ,,
Arsenic	0·039 ,,
Tin.....	0·009 ,,

The defective plate behaved very unreasonably. As already mentioned, the strips which were sheared off in the boiler yard fell to pieces, but those sheared off subsequently at the steel works were perfectly ductile and could be bent as close as any other samples. These latter samples had been sheared off the same end as the rest, and the shearing edge was comparatively new. When strips were sheared off the other edges which had not been touched since the plates left the steel works these, too, were found to be brittle. Evidently then the injury done to the extreme edge by shearing was slowly spreading into this plate, but the shears were not to blame, for the other plates were good. There was evidently something in the quality of this steel which made it sensitive to this severe treatment, and unquestionably therefore it was

not a suitable material to use, but how it acquired this peculiar quality was not discovered. Possibly the slab from which the plate was rolled had been in the rolling mill furnace for two heats instead of one; but if that was so, the men who were responsible for the blunder could not be expected to admit it.

In view of the possibility of these occurrences this Association may be congratulated on its system of check testing which seems to be specially adapted for detecting changes which may be slowly progressing. When a boiler is being built under our inspection, check tests are made with samples cut from certain plates, and these should, of course, reveal whether the material has grown brittle since it left the steel works. Check tests applied to the plates of Maginnis's boilers, or to the angles of the brittle ships previously referred to would, it is fairly safe to say, have revealed that a change for the worse was taking place.

Time Effect on Steel.

A case of great interest, but one about which full details cannot unfortunately be obtained, occurred about two years ago in Russia. Some Lancashire boilers had been at work for six years, and were annually tested by hydraulic pressure in accordance with Government regulations. On the occasion of the sixth test one boiler burst, and one year later the adjoining boiler burst. The analysis of the steel of the first boiler plate is given below. The two German results are duplicate determinations of the same sample. The English analysis was carried out on a sample recently received by me, but it is not certain that this is the same plate as the above.

TABLE VI.

	English Analysis.	German Analysis.	
	Per Cent.	Per Cent.	Per Cent.
Carbon	0·076	0·121	0·116
Silicon	trace	0·007	0·009
Sulphur	0·072	0·098	0·103
Phosphorus	0·063	0·065	0·070
Manganese	0·457	0·439	0·435
Copper	0·092	—	—
Arsenic	0·037	—	—

Although this material is not of first-class quality, one would hardly expect brittleness with a percentage of 0·121 per cent. carbon and 0·07 per cent. phosphorus; on the contrary, the analysis would lead one to expect the results which were actually obtained.

Mean tenacity 23·0 tons, elongation 28 per cent. in 8in.

A microscopic examination of this steel indicates a low percentage of carbon; but the pearlite, although scarce, occurs in very large patches, which is held to indicate that the plates had been hot and cooled slowly. After annealing the large patches break up into a large number of very small ones, and the microscopic view would seem to indicate that the material has been made ductile and mild.

Possibly the plates had been annealed after rolling for some reason or other, and injured by this process; but no information can be obtained on this point, nor would this necessarily be the best explanation, for I am in possession of a thick plate which cannot well have been annealed, but of which the microscopic structure is exceedingly coarse.

Segregation in Steel.

Engineers have frequently been puzzled by laminations in steel plates which sometimes become visible on planing, and always showed up in samples which are subjected to tension stresses, and are clearly revealed by etching, notably if a solution of from 5 to 10 per cent. of copper sulphate of ammonia is used. Under the microscope these layers are found to consist of numerous patches of pearlite whose structure indicates an excess of phosphorus. As these layers are generally near the centres of plates they are undoubtedly due to segregation, and one would expect to find the worst cases in those works where very large ingots are cast. Strange to say, that is not the case, nearly all the samples in which segregation was detected coming from works in which the ingot moulds were selected to suit the sizes of the plates to be rolled.

An analysis made of one of these plates gave the following result:—

TABLE VII.

	Central Layer about 0·10in. thick.	Two Outer Layers, Each 0·3in. thick.
Carbon	0·305	0·160
Sulphur	0·145	0·036
Phosphorus	0·190	0·088
Manganese	0·648	0·486

There are indications, which are confirmed by this analysis, that a comparatively-high percentage of phosphorus encourages segregation; at anyrate, all those samples in which segregations were marked have contained above 0·07 per cent. of phosphorus.

Grooving and Cracking of Boiler Plates.

Another class of fractures, which may possibly be influenced by the chemical composition of the material, and by improper heat treatment, is excessive and repeated straining, generally called fatigue. Plates which have been flanged round their edges, and laid aside sometimes crack when the circumferences have cooled. Thick forgings sometimes crack while being machined, and an armour plate once broke in two, evidently due to a similar cause. These, or somewhat similar results, are produced in boiler end plates and furnace flanges due to excessive heating of the furnace plates brought about in most cases by grease in the feed, and sometimes by scale. This trouble was not serious as long as boiler pressures were low and boiler plates thin and elastic, but the increased pressures demand increased strength, which, if the design is not altered, is accompanied by increased rigidity and liability to fracture.

TABLE VIII.

EXPERIMENTS ON THE LONGITUDINAL ELASTICITY OF CYLINDRICAL FLUES.

Type of Cylindrical Flue.	Material.		Dimensions.				Contraction per Single Corrugation Loaded on Circumference.			Load per Inch of Circumference when Limit was Reached.		Authority.
				Corrugations.			1 Ton per inch.		Limit.			
	Tenacity.	Elongation.	Int. Diam.	Depth.	Pitch.	Thickness. Nominal.	Actual.	½in. Plate.	¼in. Plate.	Actual.	½in. Plate	
	Tons.	%	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Tons.	Tons.	
Adamson's Flange	21·9	29·5	37·4	—	32·00	0·550	0·0138	0·0184	0·0184	1·212	1·00	v. Knaudt VI.
Fox's Corrugation	23·6	25·0	37·6	1·73	5·94	0·393	0·0265	0·0129	0·0185	0·887	1·43	,, I.
,, ,, ...	29·5	28·5	37·5	2·25	5·94	0·460	0·0235	0·0183	0·0218	1·010	1·19	,, II.
,, ,, ...	21·2	30·0	37·5	1·79	5·94	0·472	0·0184	0·0155	0·0188	1·084	1·21	,, III.
,, ,, ...	22·2	29·5	37·2	1·92	5·94	0·535	0·0126	0·0155	0·0177	1·309	1·14	,, IV.
,, ,, ...	24·4	26·0	39·1	0·98	5·94	0·393	0·0061	0·0029	0·0076	1·600	2·59	,, V.
,, ,, ...	—	—	29·9	1·58	6·00	0·386	0·0242	0·0111	0·0176	0·950	1·59	Prof. Bach.
Morrison's Corrugation.....	—	—	29·6	1·58	7·85	0·372	0·0282	0·0112	0·0221	1·200	2·17	,,
Leeds Forge (Bulb)	—	—	38·25	2·25	8·00	0·440	0·0531	0·0362	0·0331	0·708	0·91	Leeds Forge Company.
Purves (Ribbed).....	27·2	26·0	37·2	—	9·00	0·472	0·0027	0·0022	0·0116	4·220	4·73	v. Knaudt VII.
Holmes' (Single Bulbs)	—	—	29·3	3·46	24·00	0·528	0·0783	0·0920	0·0700	0·850	0·76	Prof. Bach.
,, ,, ...	—	—	29·3	3·46	24·00	0·400	0·2110	0·1080	0·0640	0·380	0·59	,,
Cylindrical Tube 6in. long (estimated)		..	..	..	..	..	..	0·0009	..	..	2·500	

A careful inquiry into our past records as to the behaviour of Lancashire boilers with corrugated flues and furnaces was made, and it was found that however bad was the treatment to which these had been subjected, no grooving had occurred, but crackings of the corrugations near the firebars were not infrequent. It was, therefore, deemed advisable to retain the plain rings for the furnaces, and to insert corrugated rings at the back ends of the flues. Inquiries revealed that whereas in Germany there is no difference in the price of boilers if fitted with flanged or corrugated furnaces and flues, in this country the extra cost for corrugated flues extending the whole length of a boiler would be from £150 to £250. It was therefore necessary to ascertain what would be the minimum length of corrugated flues of which good results might be expected. Fortunately, H. v. Knaudt, the manufacturer of corrugated flues in Germany, had made several experiments on the longitudinal elasticity of variously-shaped flues, and since then Prof. Bach and the Leeds Forge Company have made five other experiments, of which the results are contained in the preceding Table VIII.

Except in the case of Prof. Bach's experiments, for which very detailed figures are to hand, the values in the table are obtained from measurements of diagrams. They have all been reduced to a uniform standard of a plate $\frac{1}{2}$in. thick.

At first sight it would appear that there is nothing to choose between flanged and corrugated furnaces, the contraction being about equal, say 0·0185in. per pitch, but the pitch of the flanges is 32in., while that of the corrugations is only 5·93in., so that the latter are $5\frac{1}{2}$ times more elastic than the former. The elasticity is greatly influenced by depth of corrugation, as is evident on comparing the various Fox's sections and Holmes' bulb section, which are practically corrugations of 6in. pitch with 18in. flats between.

TABLE IX.

	V.	I. III. IV.	II.	2 Holmes.
	Inches.	Inches.	Inches.	Inches.
Depth of Corrugation	0·98	1·73–1·92	2·25	3·46
Compression per ton on 1 inch of Circumference	0·00294	0·0146	0·0183	0·100
Compression at Limit	0·0076	0·0183	0·0218	0·067

These results are not in perfect harmony, but they indicate that the elasticity is approximately proportional to the cube of the depth of the corrugations, and the maximum permissible compression is proportional to the square of their depths.

Elasticity of Boilers.

The next question to be settled was the amount of change of form of boilers for which elasticity had to be provided. The effect of putting a circumferential tension stress on a boiler shell and a circumferential

compression on the furnace tubes is to shorten the one and lengthen the other, the difference on 30ft. being about $\frac{1}{16}$in. When a furnace plate is covered with thick scale or with grease, it may, if the fire is intense, attain a temperature at which lead, and even zinc, will melt, say 360° Fah. hotter than the temperature of the steam, to which alone the shell plate is exposed. This excess temperature may be active over 15ft. of the furnace, and will produce an elongation of $\frac{3}{8}$in. If, therefore, the end plates of a boiler were to be made absolutely rigid one would require furnaces which would contract $\frac{7}{16}$in. without injury. If their plates were $\frac{1}{2}$in. thick there would have to be $\frac{0{\cdot}437}{0{\cdot}0185} = 24$ corrugations, or, say, 12ft. length of corrugated flue. If the plates were $\frac{3}{8}$in. thick, there need be only 10 corrugations, having a total length of 5ft. Some allowance has, of course, to be made for the 8 or 10 flanged rings and the elasticity of the end plates, but against this one has to take into account the gradual lengthening of furnace flues, which after a few years' working may exceed $\frac{1}{4}$in.

After duly considering all the above-mentioned influences the lengths of corrugated flues which would give the desired relief were adopted, and now after six years' working no grooving or front-end plate leakings of these boilers, nor cracks in the furnaces, have been reported, and that in spite of these boilers being worked hard and fed with greasy water, conditions under which ordinary high-pressure Lancashire boilers would have developed grooves before the end of the third year. The working pressures are 180lbs. and 200lbs.

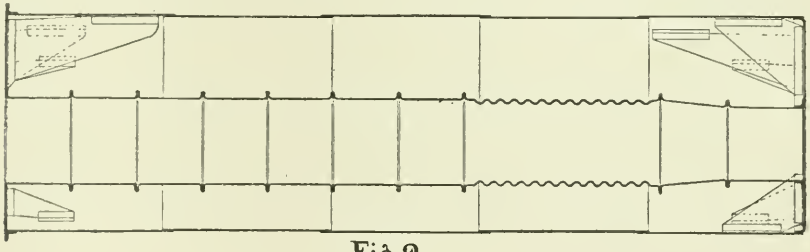


Fig 2

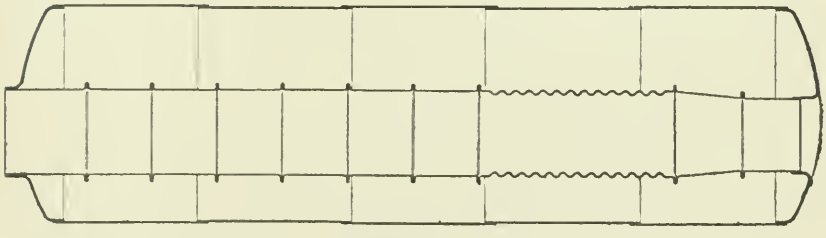


Fig 3

This type of boiler is illustrated in Fig. 2. Recently much has been said about the advantages of boilers with dished ends, and the great

preference which they enjoy on the Continent, and the question is asked, why they are not adopted in England ? The answer is that it is a question of relative cost. Dished end plates can be made cheaper than flat end plates with their shell angle rings and gusset stays, and appeal to all who dislike a multiplicity of parts. I am credibly informed that in Germany there is no difference as regards cost between flanged and corrugated flues, and the latter are naturally fitted, for experience has shown that boilers with dished ends are too rigid longitudinally if fitted with plain flues. In England, where corrugated flues are at present so much dearer than plain ones that the difference in cost would outweigh the saving which might be expected from the substitution of dished ends, it must seem desirable to determine the minimum permissible length of corrugated flues, and the above considerations will, it is hoped, be of some assistance in fixing on the right dimensions.

BOILER TRIALS.

Since the last report on trials, published in my Memorandum of 1899, several additional ones have been carried out, but before dealing with them in detail, it will be necessary to point out improvements which have been effected and carried out in the method of analysing gases and digesting the results.

Gas Analysis.

Nearly every analysis of flue gases records more than 80 per cent. nitrogen, though the atmosphere contains only about 79·04 per cent. This change of volume is due to three causes. Firstly, there is always a little nitrogen in the fuel, which is, of course, added to that of the atmosphere. Its volume can be estimated, if the coal analysis is known, by comparing the percentage there found with the carbon burnt, which is the carbon in the fuel less that in the ashes, or rather with the oxygen required for the burnt carbon, and multiplying this ratio by $1 \cdot 143 = \frac{16}{14}$, which is the ratio of the densities of oxygen and nitrogen. When the nitrogen in the fuel is not known, one may add 1 per cent. of the volume of carbonic acid found by the gas analysis.

Secondly, there is the change of volume when oxygen combines with carbon to form carbonic acid. A correction is made by adding 0·06 per cent. to the volume of carbonic acid, the sum being the volume of the oxygen consumed. This addition naturally has the effect of decreasing the apparent percentage of nitrogen.

Thirdly, when carbon is burnt to carbon monoxide, the volume of this gas is twice the volume of the oxygen consumed. The CO volume has therefore to be halved. For convenience of calculation, the process adopted is to subtract half the volume of the CO from the unconsumed oxygen, and *not* adding it to the CO volume, which then is equal to the volume of oxygen which would have been consumed if the carbon in this gas had been burnt to CO_2.

Fourthly, the fluids in the collecting gasometer may absorb some of the gases, notably the carbonic acid. To guard against this loss, which would cause an apparent increase in the volume of the nitrogen, ordinary oil should be poured into the gasometer. Floating on the water it prevents absorption almost entirely. India-rubber allows carbonic acid to pass through it with great rapidity; it is therefore very desirable to make all india-rubber pipe connections as short as possible, particularly, as will be seen later on, when continuous samples are being taken, and the collection of the gases is carried on slowly over long periods.

Fifthly, the hydrogen in the fuel consumes nearly eight times its weight (7·938) of oxygen, and as the resulting steam is not determined by the ordinary analysis the reduced volume of oxygen increases the volume of nitrogen as found by analysis.

Sixthly, the sulphur in the fuel burns to SO_2, a gas which is quickly absorbed and does not therefore appear in the gas analysis. When the ratio of sulphur to carbon is known the volume of gas lost is found by multiplying this ratio by $\frac{3}{8}$. When the percentage of sulphur is not known one may assume that the oxygen lost as H_2O and SO_2 is about 1·05 H_2O.

It would therefore be necessary to find the ratio of hydrogen in fuel to consumed carbon, or rather to the ogygen it consumes, and multiply the ratio by three times the volume of oxygen found by analysis to have been converted into carbonic acid, to which the volume of carbon monoxide is added. If the oxygen thus found be added to the analysis the total will, of course, exceed 100 plus the nitrogen from the fuel, and if all the values are proportionally reduced so that the total is brought down to 100, the nitrogen should be 79·04 per cent., or whatever percentage may have been found for air.

This process may be reversed. Subtract the nitrogen received from the fuel, reduce the remaining nitrogen to 79·04 per cent., and the unconsumed and consumed oxygen in proportion. Then subtracting the total from 100 plus the nitrogen from the fuel, the difference is the oxygen consumed by the hydrogen, and the hydrogen in the fuel is then easily determined by dividing the percentage of burnt carbon by 3 and multiplying by the ratio of the oxygen consumed by the hydrogen to the oxygen required for consumption of the carbon. Another method would be to reduce the volumes to weights by multiplying the nitrogen from the air by 0·9725, and the oxygen consumed and remaining by 1·10535, and reducing the nitrogen weight to 76·88 per cent.

The hydrogen thus found should agree with the hydrogen found by analysis of the fuel, and where there is any great discrepancy either the one or the other analysis is at fault or the sampling has not been properly carried out.

If the hydrogen in the fuel has not been determined, or cannot be determined, then, by the above-mentioned proceedings, it can be found from the change of percentage of the nitrogen. This difficulty always arises

when dealing with refuse destructors, for it is manifestly impossible to collect a sample of cinders, sweepings, straw, garden rubbish, offal, &c., and reduce it to about 30 grains weight, and yet maintain its representative character. In fact, it is very doubtful whether even with the careful system of sampling coal which is customary on trials, the small samples which have to be used for analysis and calorific determination are truly representative.

Destructor trials, from a chemist's point of view, are further complicated by the presence of a very large percentage of moisture in the refuse, and as this is evaporated in the furnace, and very materially reduces the calorific value of the refuse, it ought to be determined. In other words, if it is desired to ascertain the efficiency of a destructor, an analysis of the refuse, with the help of the gas analysis, must be carried out. This was for the first time attempted at a trial of the refuse destructor at Nelson on Tuesday and Wednesday, January 13th and 14th, 1903, and it was at once evident that an apparatus would have to be designed for determining the ratio of the moisture to the carbonic acid in the waste gases.

The ordinary gas-washing apparatus for carbonic acid does not admit of dealing with large quantities of gases, but ultimately a gas washer was designed which will easily allow 5 litres of gas to pass per hour. It has been described at a meeting of the Manchester Literary and Philosophical Society, and is illustrated in Fig. 4. The gas enters at the inlet A, which has a large vessel into which the absorbing liquid would be drawn if the suction were accidentally reversed. The gas then enters a pipe containing the absorbing fluid, and bubbling up through the coil, it carries this fluid with it, and the two thus remain in contact for a long time, say 5 to 10 seconds. On reaching the discharge vessel, which is also large enough to hold all the fluid, the two separate, the fluid returning to the junction A, and the gas passing through a chloride of calcium tube in which it parts with any moisture it may have collected in the coil. The fluid in the coil measures about 6 cc. The apparatus is weighed before and after the trial.

By using a weak caustic solution with an index one can, by noting the instant when a change of colour takes place, determine when enough carbonic acid has passed through to neutralise the caustic solution. In the Nelson trials the absorption tubes were weighed. The moisture was determined by first passing the same gas through a chloride of calcium tube, which was also weighed. The ordinary gas analysis, with the Orsat apparatus, was also carried out, and as the volume of gas drawn through absorbers was measured, two determinations of the carbonic acid were available, and led, as will be shown, to the discovery of an air leakage which on the second day amounted to about 150 per cent. of the waste gas.

Before dealing with this and other trials, it is necessary to say a word on the estimation of the weight of waste gases, without which the heat carried up the chimney cannot, of course, be calculated. The volumes

of the nitrogen and total oxygen found by analysis have to be reduced to weight percentages. This is done by multiplying the two gases by their specific weights, air being taken as 1. The specific weight of nitrogen is 0·9725, of oxygen 1·10535, and of the carbonic acid in the air 1·52. The above value for nitrogen includes argon, the correct weight for pure nitrogen being 0·96737. It is desirable to made a determination of the composition of the air at each trial, partly on account of the carbonic acid, which varies, partly because the graduations of the analysing apparatus are not always quite accurate. Then, of course, the above multipliers have to be slightly modified.

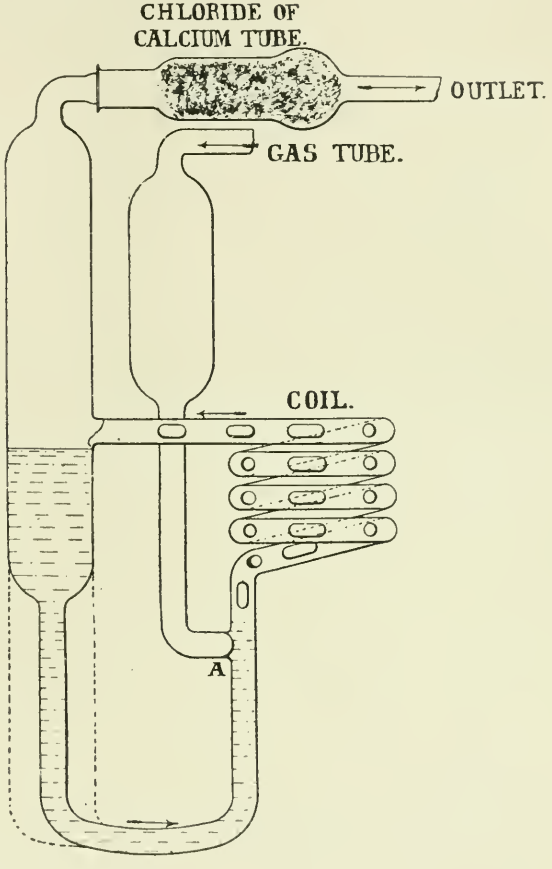


Fig 4

Having found the weights of the oxygen used for the combustion of the carbon and of the hydrogen, the weights of these elements are found by multiplying the one oxygen weight by $\frac{3}{8}$ and the other by $\frac{1}{8}$. These weights and any moisture in the fuel or steam jets have to be added to the unit weight of air, and the sum is the weight of waste gases per pound

of air supply. Dividing this ratio by the carbon found above, one gets the weight of waste gases per pound of carbon burnt, and multiplying this by the percentage of carbon burnt of the fuel, one obtains the weight of waste products per pound of fuel.

The next step is to determine the heat carried up the chimney. To this end the temperature of the waste gases has to be measured at the point where they are drawn off for analysis, and the excess temperature over that of the atmosphere has to be multiplied both by the weights and the specific heats of the constituents of the waste gas. The specific heat of air is 0·2375, that of the waste gases is generally about 0·250. The following is a list of the specific heats adopted in the trials here recorded :—

TABLE X.

Specific Heats of Gases.

Dry Air	0·2375
Oxygen	0·2438
Nitrogen	0·2175
Carbonic Acid	0·2400
Carbon Monoxide	0·2425
Steam	0·6000

The specific heat of carbonic acid varies with the temperature, $c = 0{\cdot}1846 \times 0{\cdot}000{,}075\, t°$ Fah. This is the mean value from 0 to $t°$ Fah. For rises of temperature from 60° to 500° or 700° Fah., the mean is approximately that adopted in the table. The specific heat of steam is not yet known, but it is believed to be much higher than 0·48, which was formerly considered the correct value, and 0·6000 has been adopted in these calculations.

The calorific value of a fuel can be determined by burning a sample in a calorimeter. The result is always complicated by the presence of moisture, and when a bomb calorimeter is used, this has to be found by analysis and taken into account, for in a bomb all the moisture formed is condensed at the temperature of the experiment, say 65° Fah. It is, therefore necessary to allow for the latent heat of evaporation at this temperature, viz., 1,101 B.Th.U., and not 966·6, which is the latent heat of evaporation at 212°.

According to the latest determination, the calorific value of hydrogen burnt to steam at 65° Fah. is 51,322 B.Th.U. This value diminishes at the rate of 6·5 B.Th.U. for every 1° Fah. It is, therefore desirable to state the temperature at which determinations with the bomb calorimeter are made.

The calorific value of carbon is here taken at 14,540 B.Th.U., if burnt to CO_2. If burnt to CO the value is 4,340 B.Th.U., and if the quantity of carbon monoxide which is produced from one pound of carbon be burnt to CO_2 the heat generated will be the difference, viz., 10,200 B.Th.U.

By multiplying these values into the weights of carbon and hydrogen burnt, or into those found by the gas analysis, and dividing by the specific

heat of the produced gas one obtains the initial flame temperature. This temperature is, of course, only imaginary, for the gases, even while they are burning, are being cooled; but it is useful in so far as that by dividing this initial temperature into the residue which remains when the flue gas temperature is subtracted from it, one obtains by the simplest possible process the efficiency of the boiler, from which radiation has still to be deducted. Thus, by means of a careful gas analysis, even if the composition of the fuel is not known, and by making a reasonable allowance for radiation, one can at any moment determine the efficiency of a boiler.

Destructor Trial at Nelson.

The following are the leading details of the destructor trial at the Nelson Corporation destructor works :—

The refuse was taken from exposed ashpits, and consisted principally of cinders and kitchen refuse. Offal from the slaughter-houses was also burnt in this destructor, but in view of the nature of this fuel being totally different from that burnt during the rest of the time, it was considered advisable not to complicate matters by burning this offal during the test.

The trials were carried out on Tuesday and Wednesday, January 13th and 14th, 1903. The refuse was weighed on entering the premises. A sufficient quantity to last for nearly three hours' run was tipped into the bin, and was burnt up before the next lot was tipped. The two days' trial, therefore, consisted of a series of six short ones, which can be compared amongst themselves.

The ashes drawn from the furnaces before these were recharged were placed in the yard to cool, and were subsequently weighed, sampled, and analysed. The feed-water was carefully measured by means of three tanks.

The temperatures were taken of the feed water, of the air (dry and wet bulb), of the waste gases in the side flues before entering the air heater and after leaving it, also of the air supply to the furnaces both before and after heating.

Continuous gas samples were collected and analysed at once in an Orsat apparatus, and continuous gas samples were taken from the same suction pipe, and passed through calcium chloride and potash tubes to determine both the moisture and the carbonic acid. This is an important and distinctive feature of this trial and has been fully explained above.

The temperatures in the flues were taken at different points, and interesting comparisons made. Chief amongst these is the rise of temperature of the air passing through the heater, and the fall of temperature of the waste gases; the latter being heavily charged with carbonic acid and steam, should show a smaller change than the former, the exact amount depending on the respective weights and the specific heat of steam ; but as the latter is not yet definitely known, it was useless to go through the calculations.

Table XI. gives a brief summary of those details of the two days' trial which are usually the only information that has previously been obtained from destructor trials, and it will be seen that the evaporation from and at 212° Fah. is 1·788lbs. of water per pound of refuse.

Table XII. contains details which were obtainable with the adoption of the above-mentioned methods of taking continuous gas samples, including the moisture in the waste gases. Important additions to our knowledge were thereby gained, for it was found that the refuse consisted of—

Carbon	41·5 and 52·6 per cent.
Hydrogen	0·06 and 0·10 ,, ,,

that its calorific value was 3·5 and 5·4 evaporative units, and that the waste products weighed 4·5 and 5·8lbs. per pound of refuse. These additional details have not been obtained on previous trials, and permit of a balance-sheet being struck as regards heat expenditure.

It will be seen that the heat utilised in the production of steam, exclusive of that required for the blowers, amounted to 36 per cent., which must be considered a high duty when the heat lost with the clinker drawn from the furnaces amounted to 20 per cent. With ordinary fuel, containing only a few per cent. of mineral matter, this loss would be about 2 to 3 per cent. The heat carried up the chimney was 19·3 per cent. This does not appear excessive when one remembers that the waste gases carried with them a very heavy percentage of superheated steam.

The cause of the very considerable difference for the two days of heat lost by radiation and unaccounted for, has not been satisfactorily explained; but a misunderstanding at the end of the second day's trial certainly encourages the view that the results of the first day's test are the more reliable of the two.

TABLE XI.

	Tuesday.	Wednesday.
Dates of Trial	13-1-03	14-1-03
Time of Trial	10 0—5 45	9 35—6 35
Duration of Trial ..... hours	7·75	9·00
Boiler Pressure (mean) ..... lbs.	135·1	134·2
Corresponding Temperature..... ° Fah.	358·2	357·8
Weight of Refuse Burnt During Trial ..... lbs.	45,416	43,440
Refuse Burnt per hour .....lbs.	5,837	4,532
Feed-water Supply During Trial .....lbs.	63,723	67,455
Ditto per hour .....lbs.	8.191	7,498
Ditto per pound of Refuse .....lbs.	1·419	1·555
Moisture in Steam .....per cent.	1·07	1·034
Temperature of Feed ..... ° Fah.	37·3	35·3
Evaporation per pound of Refuse from and at 212° Fah. ..... lbs.	1·698	1·877

TABLE XII.
ADDITIONAL INFORMATION.

		Tuesday.	Wednesday.
Ashes and Clinker per pound of Refuse	per cent.	43·35	37·20
Unburnt Carbon in ditto	,,	4·17	5·70
Steam Jets Supply per pound of Refuse	,,	16·22	18·70
Moisture in Air per unit of Weight	,,	0·419	0·383
TEMPERATURES.			
Air Dry Bulb	° Fah.	57·3	65·4
Air Wet Bulb.....	,,	47·6	51·2
Air Leaving Heater (mean).....	,,	325·7	336·9
Mean Rise of Temperature of Air Supply ..	,,	268·4	271·5
Waste Gases Entering Heater	,,	909·0	917·0
Waste Gases Leaving Heater	,,	610·2	680·0
Mean Drop of Temperature of Waste Gases ..	,,	298·8	237·0
Mean Increase of Temperature of Air Supply	,,	552·9	614·6

TABLE XIII.
GAS ANALYSIS BY CONTINUOUS ABSORPTION AND WEIGHING.

Time of Sampling.	Duration.	Moisture.	Carbonic Acid.	
	Minutes.	Grams.	Grams.	Per Cent. of Volume of Gas.
TUESDAY.				
10 0—12 9	129	Sample lost.	1·02342	13 246
12 25— 2 40	135	0·56654	0·79021	12 102
2 45— 5 45	180	0·92880	1·18556	11 552
WEDNESDAY.				
9 55—3 0	305	1·18394	2·00470	14·303
3 12—4 46	94	0·89125	1·80385	15·873
4 55—6 8	73	0·52279	1·19022	11·791

Then also, in consequence of a steadily-increasing air leakage into the pipes leading to the Orsat apparatus, which was not discovered until after the trial was completed, the averages given in Table XIV. have to be corrected. This is done in Table XV., in which the first two columns give the volumetric percentages of carbonic acid as found by the two methods, less the percentage of carbonic acid in the air. The third column contains a coefficient by which differences obtained by subtracting the values in Table XIV. from those obtained for the atmosphere have to be multiplied and added. These coefficients are found by dividing the differences of the carbonic acid by the carbonic acid found by the Orsat apparatus, less the carbonic acid in the air. Thus, for the first third of the experiment on Wednesday we have :—

$$n\,(9{\cdot}939 - 0{\cdot}040) = 13{\cdot}246 - 9{\cdot}939\,;\ n = 0{\cdot}3340.$$

Then the correct value for the nitrogen, whose first value according to Table XV. is 79·413, would be :—

$$N = 79{\cdot}413 + 0{\cdot}334\ (79{\cdot}413 - 79{\cdot}08) = 79{\cdot}631.$$

TABLE XIV.

CONTINUOUS VOLUMETRIC GAS ANALYSIS, BY ORSAT APPARATUS, AT THE WORKS.

Time of Sampling.	Duration.	Nitrogen.	Carbon Monoxide.	Oxygen.	Carbonic Acid.	
	Minutes.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Mean.
TUESDAY.						
Atmosphere		79·080	..	20·880	0·040	..
10 9—10 15	6	79·28	0·61	7·24	12·87	..
10 15—11 15	60	79·87	0·29	6·71	13·13	..
11 15—12 7	52	79·33	0·03	14·72	5·92	9·939
12 7—12 50	43	79·37	0·00	12·30	8·33	..
12 50—1 30	40	79·85	0·00	11·81	8·35	..
1 30—2 25 .	55	79·40	0·03	10·41	10·16	9·064
2 25—3 40	75	79·12	0·00	16·10	4·78	..
3 40—4 40	60	79·30	0·00	11·94	8·76	..
4 40—5 45	65	79·40	0·26	12·06	8·28	7·110
Averages		79·429	0.090	12·046	8·434	..
WEDNESDAY.						
Atmosphere.....		79·010	..	20·960	0·030	..
9 35—10 35	60	79·62	0.04	14·22	6·21	..
10 35—11 14	39	79·63	0·02	8·80	11·55	..
11 14—12 30	76	79·42	0·02	16·31	4·32	..
12 30—12 46	15	79·09	0·02	8·52	12·35	..
12 46— 1 43	57	79·79	0·02	12·98	7·28	..
1 43— 2 55	72	79·40	0.02	12·15	8·43	7·422
3 0—3 56	56	79·73	0·05	14·86	5·38	..
3 56—4 38	42	79·53	0·01	10·21	10·25	7·466
4 38—5 47	69	79·47	0·00	15·80	4·73	..
5 47—6 8	21	79·33	0·00	16·57	4·10	4·584
Averages		79·508	0·21	13·538	6·933	..

TABLE XV.

CORRECTIONS TO BE APPLIED TO AVERAGE RESULTS OF TABLE XIV.

Time. Approximate.		Carbonic Acid from fuel only.		Coefficient.
		By Orsat.	By Absorption.	
Tuesday	10 0—12 0	9·939	13·246	0·3340
	12 0— 2 30	9·064	12·102	0·3061
	2 30— 5 45	7·110	11·552	0·6279
		8·434	12·657	..
Wednesday	9 40—3 0	7·422	14·303	0·9307
	3 0—4 40	7·466	15·873	1·1308
	4 40—6 8	4·584	11·791	1·5826
		6·933	14·858	..

In Table XVI. this correction for the whole day has been carried out in the second column. The third column gives the volumes of oxygen consumed, the nitrogen and carbonic acid of the air remaining unchanged. In the fourth column both these gases are reduced proportionally, so that the percentage of nitrogen is that found for the air; the missing quantity is the oxygen consumed by the hydrogen of the fuel. All these volumes are in column 6 converted into weights, the multiplier being 0·9725 for nitrogen, 1·10535 for oxygen, and 1·52 for carbonic acid. The seventh column contains the weights of carbon and hydrogen from the fuel.

TABLE XVI.

	Orsat Analysis.	Corrected for Leakage.	Oxygen Consumed	Analysis Reduced to Nitrogen.	Converted to Weights.	To be Added to Last Column.
	Per Cent. Volume.	Per Cent. Volume.	Per Cent. Volume.	Per Cent. Volume.	Per Cent. Weight.	Per Cent. Weight.
Tuesday.						
Nitrogen	79·429	79·605	..	79·080	76·860	..
CO_2 in Air	0·040	0·040	..	0·040	0·060	..
,, from Fuel	8·394	12·617	..	..	..	..
,, Total	8·434	12·657	..	..	..	..
CO	0·090	0·135	..	..	..	..
O_2–½ CO Unconsumed	12·046	7·601	7·534	7·484	8·272	..
,, for CO_2	..	..	12·693	12·608	13·937	C = 5·239
,, for CO + O	..	..	0·135	0·134	0·148	C = 0·085
,, by Difference for H_2O	..	..	..	0·654	0·723	H = 0·090
Totals	100·000	99·998	—	100·000	100·000	5·414
Wednesday.						
Nitrogen	79·508	80·079	..	79·010	76·800	..
CO_2 in Air	0·030	0·030	..	0·030	0·045	..
,, from Fuel ..	6·903	14·820	..	..	..	..
,, Total	6·933	14·858	..	..	..	..
CO	0·021	0·044	..	..	..	..
O_2–½ CO Unconsumed	13·538	5·026	5·004	4·937	5·457	..
,, for CO_2	..	..	14·864	14·666	16·210	C = 6·090
,, for CO + O	..	..	0·044	0·043	0·047	C = 0·018
,, by Difference for H_2O	..	..	..	1·314	1·452	H = 0·181
Totals	100·000	100·007	..	100·000	100·011	6·289

If the refuse analysis were known, then by comparing the percentage of carbon with the weight of carbon of Table XVI. per pound of air supply, it would be easy to determine the weight of air supply per pound of refuse. As this is not known, the composition of the refuse has to be found from the gas analysis, and the weight and analysis of the ashes already given.

TABLE XVII.

WEIGHT OF WASTE GASES.

DAY OF TRIAL..	TUESDAY.	WEDNESDAY.
Carbon consumed per pound of Air.....per cent.	5·324	6·108
Carbonic Acid per pound of Air, including CO_2 from air ,,	19·236	22·345
Ratio of Total Carbonic Acid to Moisture.....	0·7549	0·5479
Estimated Weight of Moisture per pound of Air. per cent.	14·520	12·244
Carbonic Acid as above..... ,,	19·236	22·345
Carbon Monoxide (Table XVI.) ..... ,,	0·159	0·041
Nitrogen ..... ,,	76·860	76·860
Oxygen Unburnt..... ,,	8·346	5·481
Total Waste Products per pound of Air .....per cent.	119·121	116·971

Combining these deductions with information in Tables XI. and XII. the composition of the fuel is determined.

TABLE XVIII.

DAY OF TRIAL...	TUESDAY	WEDNESDAY.
Moisture supplied with Air.....per cent.	0·419	0·383
Moisture due to Hydrogen in Fuel..... ,,	0·813	1·633
By Difference Moisture from Fuel and Steam Jets ,,	13·288	10·228
Total Moisture as per Table XVII.....	14·520	12·244
Moisture in Fuel and Steam Jets from above ....per cent.	13·288	10·228
Hydrogen in Fuel ..... ,,	0·090	0·181
Carbon in Fuel Consumed to CO_2 ..... ,,	5·239	6·090
,, ,, ,, to CO..... ,,	0·085	0·018
Total A, per pound of Air.....	18·692	16·517
Ashes and Clinker .....per cent.	43·35	37·20
By Difference Moisture and Combustibles.....per cent.	56·65	62·80
Add Moisture from Steam Jets..... ,,	16·22	18·70
Total, corresponding to last Total A.....per cent	72·87	81·50
Ratio, being multiplier for previous Total	3·899	4·935
Composition of Refuse—		
Carbon Consumed to CO_2 .....per cent.	20·417	30·055
,, ,, to CO..... ,,	0·331	0·089
Carbon in Ashes..... ,,	4·170	5·700
Total Carbon in Refuse .....per cent.	24·918	35·844
Hydrogen..... ,,	0·351	0·893
Moisture ..... ,,	35·551	31·763
Mineral Matter ..... ,,	39·180	31·500
Total	100·000	100·000
Estimated Calorific Value—		
Carbon (14540) .....B.Th.U.	3623	5211
Hydrogen (51322) ..... ,,	180	458
B.Th.U.	3803	5679
Deduct Evaporation of Moisture ..... ,,	386	339
B.Th.U.	3417	5340
Evaporative Efficiency (compare Table XI.) ....per cent.	48·03	33·97

The weights of the waste gases can now be calculated by multiplying the percentages of weight of products per dry air supply with the percentage of carbon burnt, and dividing by the percentage of carbon in the waste gases. For Tuesday these percentages are 20·093 and 5·324, and for Wednesday they are 30·141 and 6·108.

TABLE XIX.

		Tuesday.		Wednesday.	
		Per Lb. of Dry Air.	Per Pound of Refuse.	Per Lb. of Dry Air.	Per Pound of Refuse.
Nitrogen	per cent.	76·860	290·07	76·800	379·02
CO_2 in Air	,,	0·060	0·23	0·045	0·22
CO_2 from Fuel	,,	19·176	72·34	22·300	110·04
Total CO_2	,,	19·236	72·57	22·345	110·26
CO	,,	0·159	0·60	0·041	0·20
Oxygen	,,	8·346	31·50	5·481	27·04
H_2O from Hydrogen	,,	0·813	3·07	1·633	8·06
Moisture from Air	,,	0·419	1·58	0·383	1·89
Moisture from Fuel	,,	9·121	33·92	6·439	31·76
Steam from Jets	,,	4·167	16·22*	3·789	18·70*
Total Moisture	,,	14·520	54·79	12·244	60·41
Total Waste Products	,,	119·121	449·53	116·911	576·93

* Note.—These values were found by direct measurement.

Multiplying the various weights of gases by their respective specific heats, and the excess temperatures over those of the atmosphere on the two days, one finds the heat carried up the chimney.

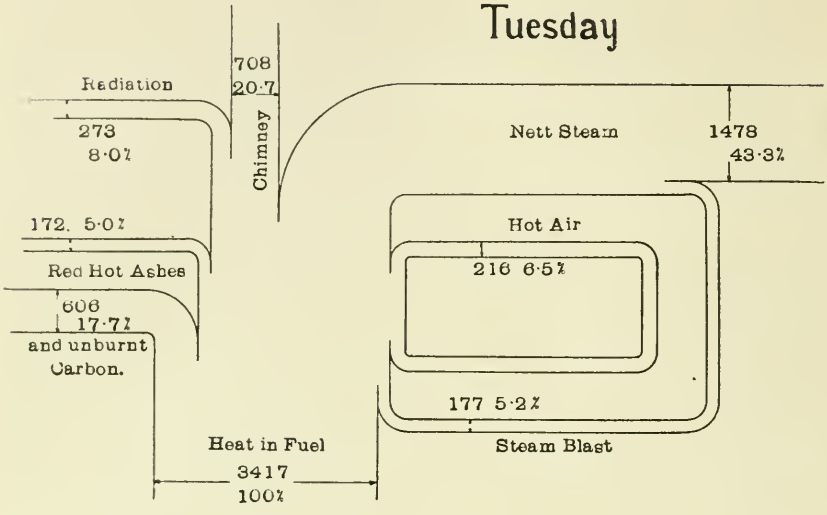
TABLE XX.

	Specific Heats.	Weights of Gases.		Heat Capacities.	
		Tuesday.	Wednesday.	Tuesday.	Wednesday.
Nitrogen (N_2)	0·2438	2·901	3·790	0·7092	0·9239
Carbonic Acid (CO_2)	0·2400	0·725	1·103	0·1732	0·2647
Carbon Monoxide (CO)	0·2425	0·006	0·002	0·0014	0·0005
Oxygen (O_2)	0·2175	0·315	0·270	0·0685	0·0587
Moisture (H_2O)	0·6000	0·548	0·604	0·3288	0·3624
Mean Specific Heats and Heat Capacities		0·2850	0·2791	1·2811	1·6102
Temperature Rises and Heat Losses		552·9°	614·6°	708·1 B.Th.U.	989·2 B.Th.U.

In the following balance-sheets, the heat lost by drawing the clinker at a red heat has been taken into account. These balance-sheets are reproduced in diagrammatic form on page 28.

Nelson Refuse Destructor Trials.

Tuesday



Wednesday

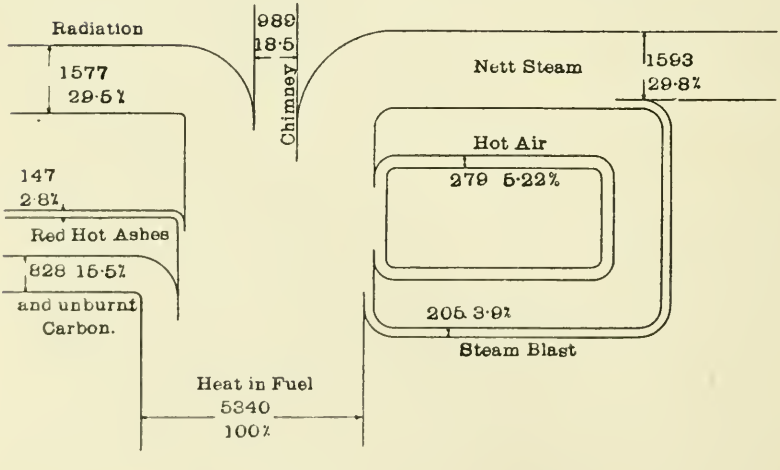


TABLE XXI.

BALANCE - SHEET.

	Tuesday.	Wednesday.	Tuesday.	Wednesday.
	B.Th.U.	B.Th.U.	Per Cent.	Per Cent.
Useful Heat in Steam	1478	1593	43·25	29·83
Heat Transferred to Steam Jets	177	205	5·18	3·84
Heat in Red-hot Ashes	172	147	5·03	2·75
Heat of Unburnt Carbon	606	828	17·74	15·51
Heat of Imperfectly-burnt Carbon (CO)	3	1	0·09	0·02
Heat of Waste Gases (Table XX.)	708	989	20·72	18·52
By Difference, Radiation, &c.	273	1577	7·99	29·53
Calorific Value (Table XVIII.).....	3417	5340	100·00	100·00

The serious discrepancy as regards radiation, &c., which is revealed by this balance-sheet naturally raises doubts as to the reliability of the observations, especially those of Wednesday, for a loss of 29·53 per cent by radiation is altogether too high. Of the various items, "heat of waste gases = 989 B.Th.U." is probably fairly correct, for it rises and falls with the total (5,340 B.Th.U.). The "heat of unburnt carbon = 828," even if incorrect will not seriously affect the result, but it should be mentioned that the high percentage of carbon in ashes on Wednesday was due to a misunderstanding at the end of that day's trial. Orders had been given to end the trial, but the firemen understood that a new lot of refuse was to be burnt without drawing the fires, and, naturally, the clinker finally drawn was richer in carbon than previous lots. In spite of this misunderstanding, the combustion was very effective; the carbon in the clinker was less than that found in boiler furnaces (compare page 34 and Tables XXXI. and XXXII.).

The item, "heat in ashes = 147 B.Th.U.," deserves special attention, for the relatively small percentage of ashes on Wednesday, viz., 37·2 per cent. (Table XVIII.), affects the whole result. Had there been 43·35 per cent., as on Tuesday, the estimated carbon and moisture would have been even less than on that day, and the efficiency higher. There was nothing to indicate that the refuse supplied on the two days differed to any material extent, and it seems strange that the ratio of clinker to carbon should vary from 1·74 on Tuesday to 1·04 on Wednesday, or nearly as seven to four. Although every care was taken to weigh all the clinker, which had been spread out to cool in a back yard, the possibility of having missed a heap cannot be entirely rejected. Another possible explanation of the above-mentioned discrepancy may be the air leakage into the gas-analysing apparatus. The connections were ordered to be solid-drawn copper pipes, but unfortunately iron gas pipes were used and probably one or more of the screwed joints were loose; at anyrate, Table XV. shows that whereas the leakage was at first only 33 per cent., it gradually rose to nearly 160 per cent. For this reason alone there would be ample justification for rejecting the results of Wednesday's trial, but they have been included as an object lesson for those engaged in boiler trials. If the

absorption apparatus had not been used in conjunction with the Orsat analyser, this leakage would not have been detected, and absolutely wrong deductions would have been drawn from the gas analysis, for the heat of the waste gases would then have appeared as if it were twice as great as it actually was, and the large percentage of oxygen would have suggested that the combustion was bad, instead of excellent, as shown in the tables.

As a check on some of these results, the changes of temperature in the air heater might have been used, but the results are more discordant than the above. This may be due to an error, as previously suggested, as to the weight of waste gases, or it may be due to an air leakage into or out of the flues, but it must be confessed that flue gas thermometry has not yet attained perfection, as will be seen from the results contained in Table XXII., which gives the details and estimates from nine economiser tests carried out by three independent experts who took the temperatures and also analysed the waste gases.

TABLE XXII.

Authority	A	B	B	C
Green's Patent Economiser.				
Mean Feed Temperature	152	148	187	155
Mean Flue Gas Temperature	573	554	556	576
Rise of Feed Temperature	199	197	173	196
Drop of Gas Temperature	312	296	263	281
Evaporation per pound of Fuel	8·36	8·61	8·41	8·52
Gas Weight per pound of Fuel from above	22·49	24·20	23·47	25·05
Ditto by Gas Analysis	22·71	23·01	24·64	27·36
Green's Circulator.				
Mean Feed Temperature	146	145	190	153
Mean Flue Gas Temperature	553	545	555	568
Rise of Feed Temperature	185	195	172	189
Drop of Gas Temperature	304	319	299	314
Evaporation per pound of Fuel	8·36	8·47	8·31	8·56
Gas Weight (from above)	21·40	21·85	20·20	21·74
Ditto by Gas Analysis	23·41	24·56	24·63	26·00
Calvert's Circulator.				
Mean Feed Temperature	153	143	..	143
Mean Flue Gas Temperature	572	515	..	534
Rise of Feed Temperature	194	172	..	172
Drop of Gas Temperature	326	300	..	269
Evaporation per pound of Fuel	8·76	8·37	..	8·60
Gas Weight (from above)	21·99	20·26	..	23·22
Ditto by Gas Analysis	23·24	24·10	..	..

Waste Gas Estimates from Economiser Trials.

The principle on which the calculations are made is as follows: The heat lost by the waste gases passing through the economiser is equal

(neglecting radiation) to the heat taken up by the feed water. The latter is equal to the rise of temperature multiplied by the weight of feed-water. The heat lost by the waste gases is equal to their weight, multiplied by their specific heats and by their drop of temperatures. If, then, the weight of feed-water per pound of fuel is known, which was the case, one can determine the weight of waste gases per pound of fuel from the changes of temperature, as well as from the gas analysis. The two determinations should agree; the table shows that they do not agree, and confining our attention to the trials made by B, it will be seen that the weights of waste gases per pound of fuel differ as 24·20 to 23·01 in one trial, and as 20·20 to 24·63 in another trial. Thus, in one trial, the gas analysis method gave a result which was 5·2 per cent. higher than that of the other method, whereas in the other trial the one result was 18 per cent. lower than the other. The uncertainty attaching to these estimates is, therefore, approximately 23 per cent. of the probable value, which, of course, invalidates such determinations, and generally throws doubts on the accuracy of the estimated heat carried away by the waste gases.

Therefore, although this two days' trial on the Nelson refuse destructor has not been as successful as wished, it is certainly a great advance on all previous trials, for they merely determined how much steam was generated per pound of refuse, whereas in this case a determination, which may be called fairly successful, was made of the composition of the refuse, and, therefore, also of its heating value.

When trials are carried out on a single line, as it were, no means exist for checking the results. In this case, however, the possibility of drawing up a balance-sheet also provides the means of detecting discrepancies which in future trials should be guarded against or reduced to a minimum. These trials should, therefore, not be judged by their discrepancies, but by the additional information they give, and in order to show how much superior they are, even to some ordinary boiler trials where the heating value of the fuel was known, it may be mentioned that Mr. Bryan Donkin's work on boiler efficiency contains several records of trials in which the sum total of heat transferred to boiler and heat carried up the chimney exceeded 112 per cent. of the available heat, so that somewhere an error of about 20 per cent. of the total heat has been made, whereas in this destructor trial a correction of only 1 per cent. of the total applied to the weight of the ashes of the second day would harmonise it with the first day.

Flue Gas Analysis at the Park Collieries, March 14th, 1903.

The object of this trial was to ascertain, without going to the trouble and expense of a complete trial, the approximate efficiency of the installation under different working conditions. It consisted of one boiler and economiser, the latter being in full use in the morning, but in the afternoon only a part of the waste gases passed through the economiser The analysis from 12-15 to 12-30 during the clinkering period, although given in Table XXIII., is not included in the mean results. The table is arranged on the same plan as Table XVI.

TABLE XXIII.

	Gas Analysis.	Oxygen Consumed.	Analysis Reduced to Nitrogen.	Converted to Weights.	Additions.
	Volume.	Volume.	Volume.		Weight.
Time 10 45—11 5 a.m.					
Nitrogen from Air.....per cent.	80·68	..	79·08	76·88	..
,, ,, Fuel, say .. ,,	0·09	..	0·09	0·09	..
CO_2 from Air, say..... .. ,,	0·03	..	0·03	0·05	..
CO_2 from Fuel ..... ,,	9·44	..	..	..	..
Carbon Monoxide, CO .. ,,	0·21	..	..	..	..
O_2 Unconsumed, $-\frac{1}{2}$ CO .. ,,	9·45	9·45	9·26	10·22	..
O_2 for CO_2 ..... ,,	..	9·50	9·31	10·28	C=3·855
O_2 for CO + O ..... ,,	..	0·21	0·21	0·23	C=0·086
By Difference, O_2 for H_2O ,,	..	..	2·11	2·33	H=0·291
Totals.....per cent.	99·90	19·16	100·09	100·08	4·232
Time, 11 16—11 56 a.m.					
Nitrogen from Air .....per cent.	80·66	..	79·08	76·88	..
,, ,, Fuel, say .. ,,	0·09	..	0·09	0·09	..
CO_2 from Air, say ..... ,,	0·03	..	0·03	0·05	..
CO_2 from Fuel ..... ,,	8·90	..	..	..	..
Carbon Monoxide, CO .. ,,	0·24	..	..	..	..
O_2 Unconsumed, $-\frac{1}{2}$ CO.. ,,	9·96	9·96	9·76	10·78	..
O_2 for CO_2 ..... ,,	..	8·95	8·77	9·68	C=3·630
O_2 for CO + O ..... ,,	..	0·24	0·24	0·26	C=0·098
By Difference O_2 for H_2O ,,	..	..	2·12	2·34	H=0·292
Totals .....per cent.	99·88	19·15	100·09	100·08	4·020
Clinkering Period.					
Time, 12 15—12 30 p.m.					
Nitrogen from Air .....per cent.	80·24	..	79·08	76·88	..
,, ,, Fuel, say .. ,,	0·05	..	0·05	0·05	..
CO_2 from Air, say ..... ,,	0·03	..	0·03	0·05	..
CO_2 from Fuel ..... ,,	4·67	..	..	..	..
Carbon Monoxide, CO .... ,,	0·10	..	..	..	..
O_2 Unconsumed, $-\frac{1}{2}$ CO .. ,,	14·96	14·96	14·74	16·27	..
O_2 for CO_2 ..... ,,	..	4·70	4·63	5·11	C=1·916
O_2 for CO + O ..... ,,	..	0·10	0·10	·11	C=0·041
By Difference, O_2 for H_2O ,,	..	..	1·42	1·57	H=0·196
Totals.....per cent.	100·05	19·76	100·05	100·04	2·153
Time, 2 45—3 45 p.m.					
Nitrogen from Air .....per cent.	80·43	..	79·08	76·88	..
,, ,, Fuel, say .. ,,	0·07	..	0·07	0·07	..
CO_2 from Air, say..... ,,	0·03	..	0·03	0·05	..
CO_2 from Fuel ..... ,,	7·07	..	..	..	..
Carbon Monoxide, CO .... ,,	0·10	..	..	..	..
O_2 Unconsumed, $-\frac{1}{2}$ CO .. ,,	12·25	12·25	12·04	13·30	..
O_2 for CO_2 ..... ,,	..	7·11	6·99	7·71	C=2·891
O_2 for CO + O ..... ,,	..	0·10	0·10	0·11	C=0·041
By Difference, O_2 for H_2O ,,	..	..	1·76	1·94	H=0·242
Totals .....per cent.	99·95	19·46	100·07	100·06	3·174

The ratios of the burnt hydrogen and carbon in the fuel are therefore 7·38, 7·83, 10·02, and 8·25 per cent. respectively. The weight of waste gases per pound of carbon burnt is 26·47, 28·17, 52·21, and 35·21 per cent. respectively. Per pound of fuel, these numbers would have to be decreased in proportion to the carbon in the fuel, which was not determined. Per pound of carbon, which would be contained in, say, 1½lbs. to 1¾lbs. fuel, the calorific value is about 18,600 B.Th.U. Dividing this by the weight of waste gases and their specific heat (say 0·250) the initial flame temperatures would be about 2,723° Fah. in the morning and 2,113° Fah. in the afternoon.

The temperatures observed at various points are contained in Table XXIV.

TABLE XXIV.

	Waste Gases.		Feed Water.		Changes of Temperature.	
	Entering.	Leaving.	Entering.	Leaving.		
	Economiser.		Economiser.		Gases.	Feed.
Morning .....deg. Fah.	742	502	112	222	240	110
Afternoon ..... „	873	799	103	156	74	53

Allowing 10 per cent. for radiation of boiler and economiser, the efficiencies are found to be 71·6 and 52·2 per cent. for the morning and afternoon. This great difference is due partly to the greater volume of air admitted in the afternoon, which resulted, as has been previously shown, in an increase of the waste-gas temperature. Some of this wasted heat might have been absorbed by the economiser, but it was only partly open, hence the great difference, nearly 300° Fah., between the morning and afternoon temperatures of the waste gases entering the chimney.

Although, therefore, the coal consumption was believed to be 12 per cent. greater in the afternoon than in the morning, due to increased draught, this was dearly paid for by a reduction of efficiency of 27 per cent., due partly to worse conditions of firing, partly to less heat being taken up by the economiser.

Boiler Trial at Salford Electricity Works.

Only the gas analysis were taken by this Association; the fuel and feed water were measured by the Corporation engineers. The gases were collected, as nearly as possible, continuously, and every time that a gasometer was filled it was analysed on the spot. The results corrected for temperature are contained in Table XXV.

TABLE XXV.

No. of Sample.	Time of Collecting Sample.	Time Interval.	N_2	CO.	O_2	CO_2
		Min.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	9 45—10 10	25	80·56	0·04	11·85	7·55
2	10 22—10 55	33	80·70	0·01	10·99	8·30
3	11 10—11 25	15	80·91	0·00	8·84	10·25
4	11 45—12 8	23	81·10	0·06	8·66	10·18
5	12 27— 1 0	33	81·28	0·00	8·52	10·20
6	1 15— 2 0	45	81·10	0·05	8·26	10·59
7	2 15— 2 50	35	80·88	0·22	8·16	10·74
8	3 8— 3 50	42	81·13	0·07	8·06	10·74
9	4 4— 4 50	46	81·10	0·00	8·38	10·52
10	5 10— 5 57	47	80·73	0·02	9·40	9·85
11	6 13— 7 3	50	80·71	0·10	9·55	9·64
12	7 38— 8 30	52	81·08	0·08	9·19	10·65
13	8 38— 9 30	52	80·62	0·00	11·08	8·30
Totals and Means		498	80·910	0·052	9·186	9·848

The fuel analysis was as follows:—

TABLE XXVI.

	Per Cent.
Ash	8·06
Carbon	72·48
Sulphur (combustible)	2·32
Nitrogen	1·72
Hydrogen	3·94
Moisture (including H_2 and O in fuel)	11·48
Total	100·00

As the ashes contained 13·48 per cent. carbon, 1·26 per cent. has to be subtracted from the above, leaving 71·22 per cent. carbon, and for the purpose of the flue gas analyses $\frac{3}{8}$ S has been added, making 72·09 per cent., but from remarks made above it is doubtful whether this is permissible. The nitrogen in the fuel has to be allowed for by multiplying the carbonic acid percentages by $\frac{3}{7}\frac{1·72}{72·09} = 0·01023$.

According to the analysis, the atmosphere contained nitrogen 79·00, carbonic acid 0·04, and oxygen 20·96 per cent. Dealing with the analyses as in previous cases, the results are as follows:—

TABLE XXVII.

No. of Sample.	Nitrogen from		CO_2 from	Oxygen			
	Air.	Fuel.	Air.	in CO_2	in CO+O.	Unconsumed less ½ CO.	Total.
1	0·075	80·485	0·040	7·586	0·040	11·830	19·425
2	0·083	80·617	0·040	8·760	0·010	10·985	19·755
3	0·102	80·808	0·040	10·271	0·000	8·840	19·111
4	0·102	80·998	0·040	10·201	0 060	8·630	18·891
5	0·102	81·178	0·040	10·221	0·000	8·520	18·741
6	0·106	80·994	0·040	10·613	0·050	8·235	18·898
7	0·107	80·773	0·040	10·764	0·220	8·149	19·133
8	0·107	81·023	0·040	10·764	0·070	8·025	18·859
9	0·105	80·995	0·040	10·543	0·000	8·380	18·923
10	0·098	80·632	0·040	9·869	0·020	9·390	19·279
11	0·096	80·614	0·040	9·658	0·100	9·545	19·303
12	0·106	80·974	0·040	9·674	0·080	9·150	18·904
13	0·083	80·537	0·040	8·310	0·000	11·080	19·390

TABLE XXVIII.

Number of Sample	1	2	3	4	5	6	7	8	9	10	11	12	13
	%	%	%	%	%	%	%	%	%	%	%	%	%
Volume N_2 from Air	79·000	79·000	79·000	79·000	79·000	79·000	79·000	79·000	79·000	79·000	79·000	79·000	79·000
„ N_2 from Fuel	0·073	0·080	0·099	0·099	0·099	0·103	0·104	0·104	0·102	0·095	0·093	0·103	0·080
„ CO_2 from Air	0·040	0·040	0·040	0·040	0·040	0·040	0·040	0·040	0·040	0·040	0·040	0·040	0·040
„ O_2 Unconsumed–$\frac{1}{2}$ CO	11·613	10·765	8·642	8·417	8·292	8·035	7·970	7·825	8·173	9·200	9·353	8·926	10·865
„ O_2 for CO_2	7·446	8·583	10·040	9·956	9·945	10·358	10·528	10·496	10·283	9·668	9·465	9·437	8·149
„ O_2 for CO + O	0·040	0·010	0·000	0·059	0·000	0·050	0·215	0·068	0·000	0·020	0·098	0·079	0·000
By Difference O_2 for H_2O	1·861	1·602	2·278	2·528	2·723	2·517	2·247	2·571	2·504	2·072	2·044	2·518	1·946
Weight N_2 from Air	76·830	76·830	76·830	76·830	76·830	76·830	76·830	76·830	76·830	76·830	76·830	76·830	76·830
„ N_2 from Fuel	0·071	0·078	0·096	0·096	0·096	0·100	0·101	0·101	0·099	0·092	0·090	0·100	0·078
„ CO_2 from Air	0·060	0·060	0·060	0·060	0·060	0·060	0·060	0·060	0·060	0·060	0·060	0·060	0·060
„ O_2 Unconsumed–$\frac{1}{2}$ CO. .	12·804	11·871	9·529	9·280	9·143	8·859	8·787	8·628	9·013	10·144	10·314	9·842	11·980
„ O_2 for CO_2	8·211	9·464	11·070	10·978	10·965	11·421	11·609	11·573	11·337	10·660	10·435	10·405	8·985
„ O_2 for CO + O	0·044	0·011	0·000	0·065	0·000	0·055	0·237	0·075	0·000	0·022	0·108	0·087	0·000
„ O_2 for H_2O	2·051	1·766	2·511	2·787	3·002	2·775	2·477	2·834	2·760	2·284	2·253	2·776	2·145
„ C for CO_2.....	3·079	3·549	4·151	4·117	4·114	4·283	4·353	4·340	4·251	3·997	3·913	3·902	3·370
„ C for CO	0·016	0·041	0·000	0·024	0·000	0·021	0·089	0·028	0·000	0·068	0·039	0·033	0·000
„ Hydrogen for H_2O	0·256	0·221	0·314	0·348	0·375	0·347	0·309	0·354	0·345	0·285	0·282	0·345	0·268
Total Waste Gases per lb. of Air	103·422	103·889	104·561	104·585	104·585	104·751	104·832	104·823	104·695	104·382	104·324	104·380	103·716
Total Carbon per pound of Air	3·095	3·590	4·151	4·141	4·114	4·304	4·422	4·368	4·251	4·005	3·952	3·935	3·370
Total Waste Gases per lb. Fuel	24·09	20·86	18·16	18·21	18·33	17·55	17·09	17·30	17·75	18·58	19·03	19·12	22·19
Estimated Hydrogen in Fuel ..	5·99	4·47	5·27	6·06	6·57	5·82	5·03	5·84	5·86	5·14	5·15	6·42	5·73

Table XXVIII. shows how the several calculations have been carried out. In the upper portion are all the constituents found by analysis, but reduced so that the nitrogen from the air equals 79·00 as previously found ; then the oxygen consumed by the hydrogen is found by difference. The lower portion of the table contains these constituents reduced to weights, by multiplying the nitrogens by 0·9725 and the oxygens by 1·10535.

The heat capacities and the heat carried away by the waste gases, &c., are not given, as the coal and feed measuring was not carried out by this Association. The table is of interest as showing how closely the hydrogen determined by gas analysis agrees with that found in the small sample of fuel. The slight difference, which cannot be accounted for by leakage, may possibly be due to a discriminating action of the newly-formed smoke particles in absorbing perhaps relatively more of carbonic acid than of the other constituents. An interesting feature of this trial is that if the estimated hydrogen be plotted in a curve over the duration of the trial it will be found that a distinct change took place every two hours, as if, after each interval, there had been a change of fuel. Thus the hydrogen was above the average from 11–30 to 1–30, from 3–10 to 5–10, and from 7–30 to 9–30, and below the average during the rest of the time.

Boiler Trial at Messrs. Barclay, Perkins, & Co.

A seven-days' trial was carried out at Messrs. Barclay, Perkins, & Co.'s Brewery (from 23rd to 31st March, 1903) in order to test a recently-installed underfeed stoker. The firm had already tested the boiler for one week while being fired by hand, but as certain conditions had to be fulfilled by the stoker, this Association was called in to make independent observations. The economic results obtained are therefore not strictly comparable, and will not be referred to ; but during the second trial samples of gas were analysed, and the results are of interest. The fuel analysis was as follows :—

TABLE XXIX.

	Slack.	Anthracite.
Carbon ..... per cent.	69·86	87·78
Hydrogen ..... ,,	4·44	3·36
Moisture ..... ,,	4 19	1·58
Ash ..... ,,	8·48	4·87
Oxygen, Nitrogen, &c. ..... ,,	13 03	2·41
Per cent.	100·00	100·00
Calorific Value of Fuel..... B.Th.U.	11,690	13.882

The percentage of ash and clinker taken from the furnaces was 7·45, 10·35, and 9·09 for the slack, giving a mean of 8·96 per cent. The weight of ashes for the hand-fired boiler was not ascertained. The ashes were not analysed, and in estimating the weight of waste gases it has been assumed that the ashes contained no carbon. The correct weight of waste gases will therefore be slightly less than that given.

TABLE XXX.

MEANS OF FOUR SETS OF CONTINUOUSLY-COLLECTED SAMPLES OF FLUE GAS.

Fuel and Firing Conditions.	Slack Burnt on Underfeed Stoker.			Anthracite. Hand-fired.
Day and Date.	Tuesday. 24-3-03	Wednesday. 25-3-03	Thursday 26-3-03	Thursday. 26-3-03
Duration of Sampling ..... minutes	482	583	400	400
Volume.	Per cent.	Per cent.	Per cent.	Per cent.
Nitrogen	80·400	82·320	82·085	80·995
Carbon Monoxide	0·171	0·015	0·011	0·011
Oxygen	10·240	8·472	6·656	12·449
Carbonic Acid	9·072	9·199	11·264	6·559
Totals	99·883	100·006	100·016	100·015
N_2 from Fuel, say $\frac{1}{100}$ CO_2	0·091	0·092	0·113	0·066
CO_2 from Air, say 0·03 per 100	0·030	0·031	0·031	0·030
O_2 required for CO	0·085	0·007	0·005	0·005

Instead of reducing all these values first to correct volumes of oxygen consumed, then to volumes corresponding to nitrogen = 79·08, and then converting these into weights, the whole process can be carried out direct even without reducing the above to 100. Thus on Tuesday 0·091 has to be subtracted from the nitrogen for the assumed nitrogen from the fuel, leaving 80·319; this has to equal 76·88 by weight, so

TABLE XXXI.

WASTE GAS CONSTITUENTS BY WEIGHT.

Fuel and Firing Conditions.	Slack Burnt on Underfeed Stoker.			Anthracite. Hand-fired.
Day of Trial	Tuesday.	Wednesday	Thursday.	Thursday.
	Per cent.	Per cent.	Per cent.	Per cent.
Nitrogen from Air	76·880	76·880	76·880	76·880
„ from Fuel, say	0·087	0·086	0·106	0·063
Carbonic Acid from Air, say	0·046	0·046	0·046	0·046
Oxygen Unconsumed – $\frac{1}{2}$ CO	11·019	8·972	7·075	13·407
„ for CO+O	0·186	0·016	0·012	0·012
„ for CO_2	9·903	9·800	12·046	7·073
„ for H_2O by Difference	1·966	4·286	3·941	2·582
Total	100·087	100·086	100·106	100·063
Carbon for CO	0·033	0·033	0·040	0·024
„ for CO_2	3·718	3·675	4·517	2·653
Total Carbon	3·751	3·708	4·557	2·677
Hydrogen	0·246	0·536	0·468	0·323
Total Waste Gas per pound of Air ..	104·084	104·320	105·121	103·063
„ „ „ „ Fuel ..	19·38	19·66	16·12	33·80
Estimated Hydrogen in Fuel.....	4·58	10·10	7·17	10·59

that the coefficient is 0·9573, and as oxygen is about 1·1364 times heavier than the nitrogen of the air, the coefficients for the unconsumed oxygen and for the carbon monoxide is 1·088, and for the carbonic acid from the fuel it is 1·0917. The coefficients for the three other trials are nitrogen 0·9343, 0·9378, and 0·9500; oxygen and carbon monoxide, 1·062, 1·066, and 1·080, and for carbonic acid 1·0656, 1·0690, and 1·0785.

This trial was carried out before the possibility of utilising the gas analysis for the determination of the hydrogen had been decided upon, and as the estimates are much higher than the fuel analysis it is evident that there must have been a loss of carbonic acid. This occurred probably through the india-rubber tubes which were rather long, especially on the Wednesday and Thursday. This view is supported by the fact that whereas the average time of filling one gasometer was 70 minutes on Tuesday, the time was 200 minutes on the other days. The leakage of carbonic acid, no matter how it may have been caused, seems to have been more than 1 per cent. during the two last days, whereby the estimated weight of waste gases and the heat lost up the chimney would be affected about 10 per cent.

This case once more demonstrates the necessity of adopting every precaution for preventing leakage or absorption of carbonic acid, and where there is any doubt on the subject it will evidently be well to ignore the CO_2 determination altogether and, making reasonable allowances for hydrogen and nitrogen in the fuel, rely on the measured volumes of the oxygen and nitrogen, reducing the latter to, say, 79·08 vols. or 76·88 grams, which are its percentage in the air. The rule for finding the excess air over that required for perfect combustion would be to multiply the oxygen found by 79·08 and divide by the nitrogen found, less an allowance for nitrogen in the fuel, and to divide this quantity by the percentage remaining after deducting it from 20·8.

Thus:—

$$\frac{\text{Excess air}}{\text{required air}} = 79{\cdot}08\,\frac{O}{N}\,\frac{1}{20{\cdot}92 - 79{\cdot}08\,\frac{O}{N}}$$

Trial of a Boiler at the Haydock Colliery, carried out for the purpose of ascertaining the merits of the Hotchkiss Circulator, and also the merits of the Meldrum Stoker.

The first trials took place on Tuesday to Thursday, February 9th to 11th, 1904, and the second trials took place on Wednesday and Thursday, February 24th and 25th, 1904.

During the first trials slack, which had passed through 1¼in. screen, was fired by hand; during the second trials small slack, which had passed through a ⅜in. screen, was burnt on a Meldrum grate, and a steam blast was used. The steam was supplied from a separate donkey boiler, and the quantity used has been deducted from the steam generated by the main boiler. On Thursday, February 11th, the Hotchkiss circulator was used.

No economisers were used, and as the boiler was heavily worked, the efficiencies were fairly low.

The boiler was of the Lancashire type, and one of a range of five. It was 8ft. diam., and 30ft. long, set in the ordinary manner. During the trial a separate feed pump was worked for this boiler, and the water was drawn from measuring tanks. The fuel had been weighed into sacks and the times were noted whenever two additional cwts. had been burnt. The firing was maintained at a constant rate, any variations in the steam demand being met by changes in the four adjoining boilers. Fires were cleaned 1½ hours before starting, and again 1½ hours before ending the trial.

The fuel was sampled throughout the trial, and the carbon, hydrogen, moisture, and ashes determined. The ashes were also analysed for carbon.

The feed water was measured in tanks, and every quarter of an hour readings were taken of the water level in the boiler, and the boiler pressure, so that the heat transferred is known for each quarter of an hour. The steam was tested for moisture and the necessary allowances made. The moisture of the steam used for the blower was very high, being 4 per cent. at the boiler and 13·7 per cent. at the furnace. This heavy condensation was due to the cold weather, which must also have affected the temperature of the main boiler feed.

The flue gases were analysed continuously, their temperatures taken, and allowance made for the steam introduced by the blowers. On account of the gases from this boiler being delivered into the main flue into which four other boilers were discharging, the pyrometers were placed in the side flues, where they were subjected to radiation from the downtake; their readings therefore are doubtless a little too high, and so is the estimated chimney loss, while the radiation found by difference is probably a little too low.

On Wednesday of the first trial the combustion was less perfect than on other days, as revealed by the relatively large percentage of carbon monoxide.

This trial, although unsuitable for comparison with the others, is

TABLE XXXII.

Fuel and Firing Conditions.	Slack (1¼in. screen), Hand-fired.			Small Slack. Meldrum's Mechanical Stoker.	
Days and dates ..... February, 1904	Tues. 9th.	Wed. 10th.	Thurs. 11th.	Wed. 24th.	Thurs. 25th.
Times and Durations of Trial .. Hours....	10 0—6 0 8	9 15—5 15 8	9 0—5 0 8	9 45—5 45 8	9 15—5 15 8
Steam Pressure, mean....lbs.	78·6	82	86·9	82·4	85·6
Fuel Analysis.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Moisture at 212° Fah.....	6·627	6·401	6·783	7·087	6·393
Volatile Matter	26·401	28·620	27·730	25·342	26·799
Fixed Carbon.....	55·268	55·143	53·452	47·118	51·784
Mineral Matter	11·704	9·836	12·035	20·453	15·023
Total	100·000	100·000	100·000	100·000	100·000

TABLE XXXII—*continued.*

Fuel and Firing Conditions.	Slack (1¼in. screen), Hand-fired.			Small Slack. Meldrum's Mechanical Stoker.	
Carbon	65·62	66·37	64·33	57·05	62·29
Hydrogen	4·29	4·65	4·50	4·11	4·35
Mineral Matter	11·70	9·84	12·03	20·45	15·02
Moisture at 212° Fah.	6·63	6·40	6·78	7·09	6·39
By Difference N, S, O, &c.	11·76	12·74	12·36	11·30	11·95
Total	100·00	100·00	100·00	100·00	100·00
Calorific Value (Bomb Calorimeter)	B.T.U. ..	B.T.U. 12,526	B.T.U. ..	B.T.U. ..	B.T.U. 11,340
Estimated Calorific Value—					
Carbon (14,540)	9,541	9,650	9,353	8,295	9,057
Hydrogen (51,322)	2,202	2,387	2,312	2,110	2,233
	11,743	12,037	11,665	10,405	11,280
Less Moisture at 65° Fah. (1,100)	66	64	68	71	64
Total Calorific Value at 65° Fah.	11,677	11,973	11,597	10,334	11,216
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Ashes, &c., Coal	14·48	12·53	13·34	8·38	7·86
,, Carbon	8·43	16·55	14·65	8·02	8·82
,, Mineral Matter	77·09	70 92	72·01	83·60	83·32
Total	100·00	100·00	100·00	100·00	100·00
Composition per pound of Fuel..					
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Mineral Matter (as above)	11·70	9·84	12·03	20·45	15·02
Total Carbon in Ashes and Small Coal	2·72	3·45	3·88	3·08	2·47
Carbon Actually Burnt	62·90	62·92	60·45	53·97	59·82
Fuel Burnt during Trial..lbs.	9,296	7,392	8,624	8,176	10,192
,, ,, per hour ,,	1,162	924	1,078	1,022	1,274
,, ,, ,, per square foot of grate area	30·58	24·31	28·37	26·90	33·52
Feed Water during Trial..lbs.	57,424	46,529	54,430	48,105	61,891
,, ,, for Steam Jets ,,	..	..	..	2,158	2,346
,, ,, net ,,	57,424	46,529	54,430	45,947	59,445
Feed per hour, gross ,,	7,178	5,816	6,804	6,013	7,736
Net Feed per pound of Fuel ,,	6·18	6·29	6·31	5·88	6·07
Moisture in Steam ....per cent.	1·88	1·41	1·40	1·18	1·55
Temperature of Feed deg. Fah.	152	158	161	163	148
,, Steam ,,	323	324	329	326	328
Net Feed per pound of Fuel at and from 212° Fah. ....lbs.	6·67	6·79	6·82	6·33	6·61
Flue Gases—					
Temperature .....deg. Fah.	930	705	841	751	845
Analysis, Duration of Sampling, Minutes	..	360	420	420	420
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nitrogen ..... Volume	81·06	80·83	80·62	80·73	80·57
Oxygen ,,	10·11	6·23	10·73	12·38	11·49
Carbonic Acid ,,	8·74	11·40	8·35	6·85	7·80
Carbon Monoxide ,,	0·09	1·54	0·30	0·04	0·14
Total	100·00	100·00	100·00	100·00	100·00

of special interest, for although the reduced air supply resulted in incomplete combustion, which was ascertained to be 15 per cent. in excess of that of other days, yet the reduced air volume gave up its heat more readily than on other days, and the heat carried off by the waste gases was reduced by almost as much as that lost by incomplete combustion.

Before starting the trials an analysis was made of the flue gases, when it was found that nearly four times the theoretical quantity of air was being admitted to the furnaces; improvements were effected before a definite start was made.

The details of the five trials are given in the form of diagrams, pp. 43–47, and the general results are given in Table XXXII.

Either by converting the constituents first into volumes and then into weights, or by the shorter method carried out in the calculation of Messrs. Barclay, Perkins, & Co.'s results, the gas and fuel analysis is made use of in Table XXXIII., in which the percentage of hydrogen in the fuel is estimated as well as the weight of waste gases per pound of fuel and their specific heats.

TABLE XXXIII.

Firing Conditions	Hand Fired.			Mechanical Stoker.	
Date, February, 1904	9th.	10th.	11th.	24th.	25th.
	Weight, Per cent.	Weight, Per cent.	Weight, Per cent.	Weight, Per cent.	Weight, Per cent.
Nitrogen from Air	76·837	76·837	76·837	76·837	76·837
,, from Fuel (say)	0·083	0·109	0·079	0·065	0·074
Carbonic Acid from Air (say) ..	0·045	0·045	0·045	0·045	0·045
Oxygen Unconsumed + $\frac{1}{2}$ CO ..	10·835	5·890	11·441	13·350	12·364
,, for CO_2	9·466	12·375	9·089	7·444	8·496
,, for CO + O.....	0·097	1·662	0·324	0·043	0·151
,, for H_2O by Difference	2·719	3·182	2·258	2·280	2·106
Total	100·082	100·109	100·075	100·064	100·073
Carbon for CO_2	3·551	4·640	3·409	2·792	3·187
,, for CO	0·036	0·623	0·121	0·016	0·057
Total Carbon per pound of Air..	3·587	5·263	3·530	2·808	3·244
Hydrogen for H_2O.....	0·339	0·398	0·282	0·285	0·263
Total Dry Waste Gases per pound of Air.....	104·008	105·760	103·887	103·157	103·580
Moisture due to Hydrogen	3·061	3·583	2·542	2·567	2·371
,, from Fuel	0·379	0·756	0·395	0·363	0·343
,, from Steam Jets	..	..	..	1·181	1·201
Total Waste Gases per pound of Air	104·387	106·516	104·282	104·701	105·124
Total Waste Gases per pound of Fuel	18·31	12·64	17·86	20·13	19·38
Estimated Hydrogen in Fuel ..	5·944	4·758	4·829	5·478	4·850
Mean Specific Heat of Waste Gases	0·2524	0·2560	0·2504	0 2541	0·2535

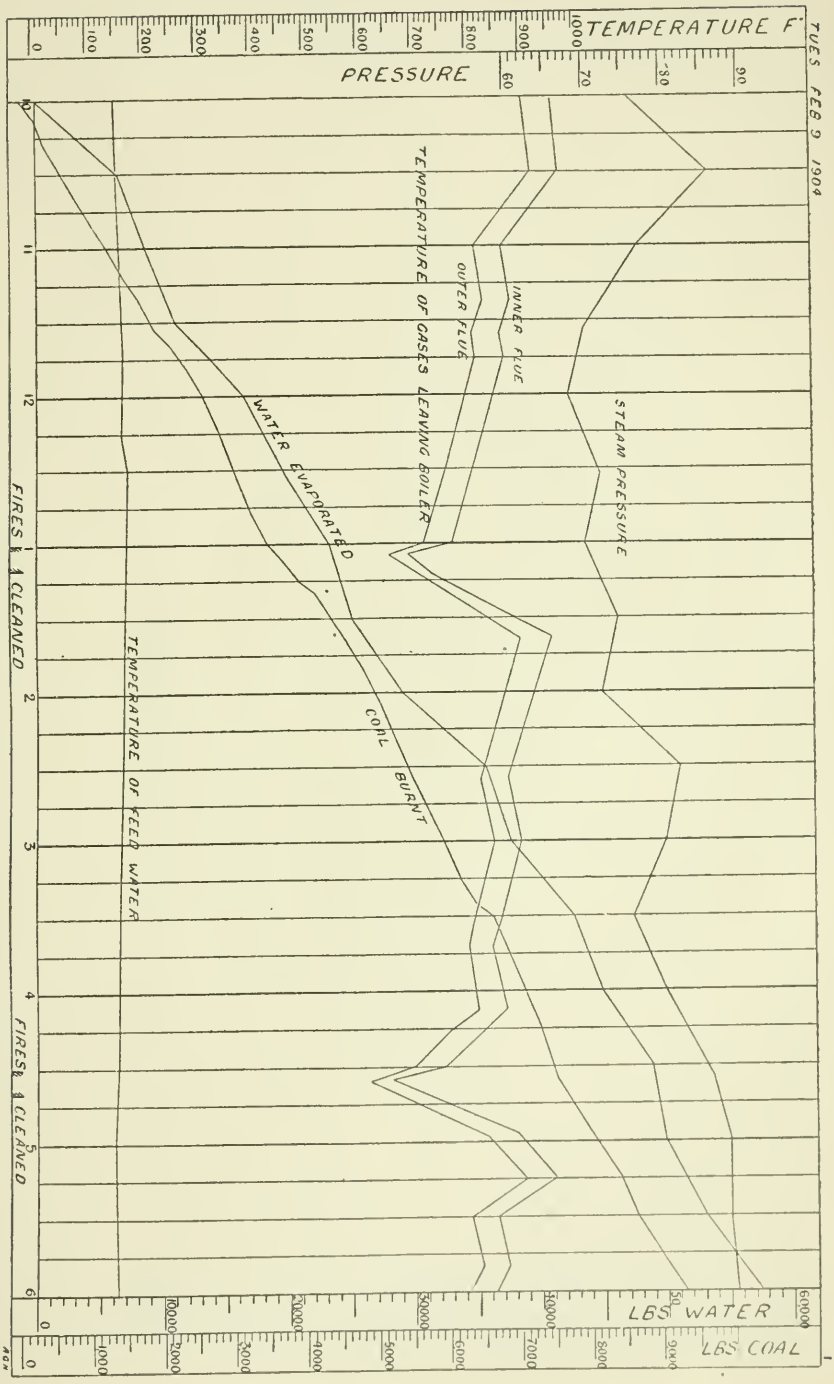
From the information contained in Tables XXXII. and XXXIII. the balance-sheets of Table XXXIV. and the diagrams pp. 48–49 have been prepared. The estimated calorific values have been adopted because the experimental ones were taken for only two days; besides, when allowance is made for evaporation of the moisture which is condensed in the bomb, which amounts to more than 100 calories, the two results of the first Wednesday do not differ materially, and those for the last Thursday are in practical agreement.

TABLE XXXIV.

Balance-sheet of Heat Account.

Fuel and Firing Conditions	Slack, Hand-fired.			Small Slack. Meldrum's Stoker.	
Date, February, 1903	9th.	10th.	11th.	24th.	25th.
	B.Th.U.	B.Th.U.	B.Th.U.	B.Th.U.	B.Th.U.
Heat Transferred to Water	6,444	6,558	6,586	5,870	6,176
,, for Steam Jets	..	..	..	295	253
,, in Waste Gases.....	3,986	2,090	3,484	3,567	3,872
,, Due to Incomplete Combustion	66	751	212	32	108
,, of Unburnt Fuel in Ashes	417	611	528	318	273
By Difference, Radiation, &c. ..	764	1,963	787	252	534
Heat in Fuel (Table XXXI.) ..	11,677	11,973	11,597	10,334	11,216
	Per cent.	Per cent	Per cent.	Per cent.	Per cent.
Heat Transferred to Water	55·19	54·77	56·80	56·80	55·07
,, for Steam Jets	..	..	..	2·85	2·25
,, in Waste Gases	34·14	17·46	30·05	34·51	34·53
,, Due to Incomplete Combustion	0·56	6·28	1·82	0·31	0·96
,, of Unburnt Fuel in Ashes	3·57	5·10	4·55	3·07	2·43
By Difference: Radiation, &c.	6·54	16·39	6·78	2·44	4·76
Total	100·00	100·00	100·00	100 00	100·00

These balance-sheets, which are given in a diagrammatic form, pp. 48–49, in spite of slight discrepancies, are highly satisfactory. As already pointed out, the reduction of the fuel to a sample of about one two-millionth of the total is not a very satisfactory arrangement for determining the average composition and calorific value. This is borne out by this trial, for there is no reason to believe that the quality of the slack differed as much as would appear during the first three days, and again during the last two days, and if average values of the respective sets had been taken, as was done in the case of Messrs. Barclay, Perkins, & Co.'s trial, the results, as revealed by "radiation, &c.," would have been even more consistent. Even then, however, the trial of February 10th would have shown a loss of 14 per cent. by radiation and unaccounted for, or about 7 per cent. more than might reasonably be expected.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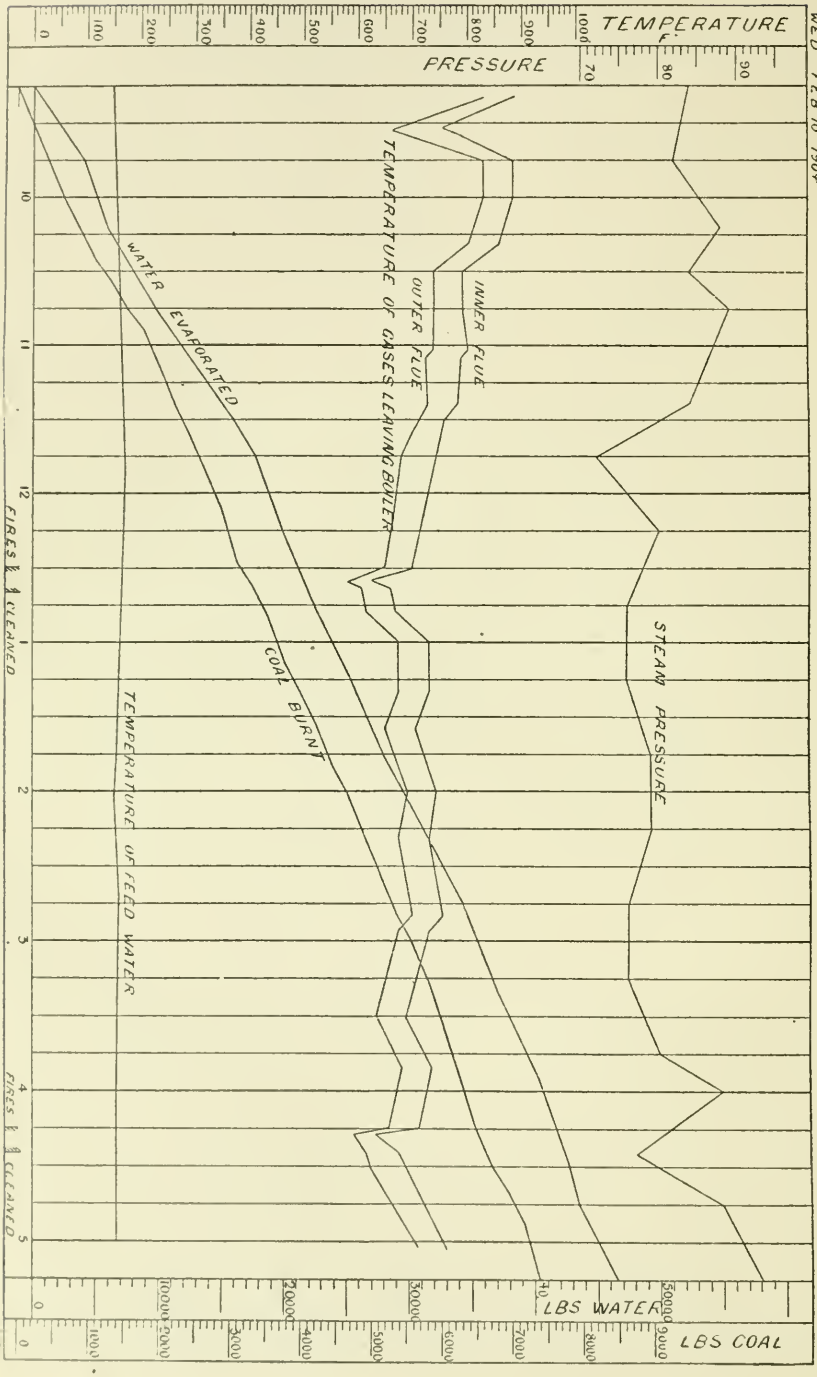
TEMPERATURE F°
PRESSURE
TEMPERATURE OF GASES LEAVING BOILER
OUTER FLUE
INNER FLUE
STEAM PRESSURE
WATER EVAPORATED
COAL BURNT
TEMPERATURE OF FEED WATER
FIRES CLEANED
FIRES CLEANED
LBS WATER
LBS COAL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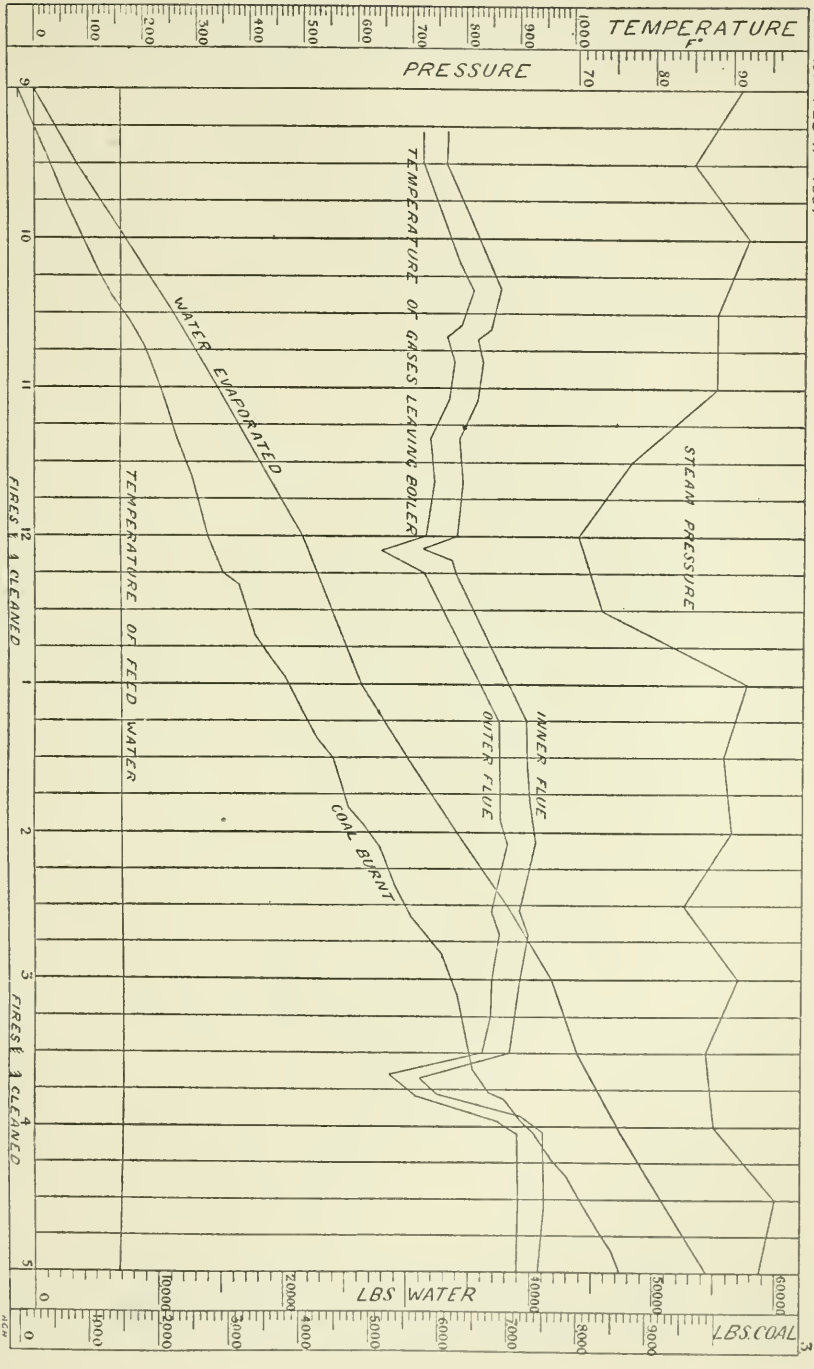
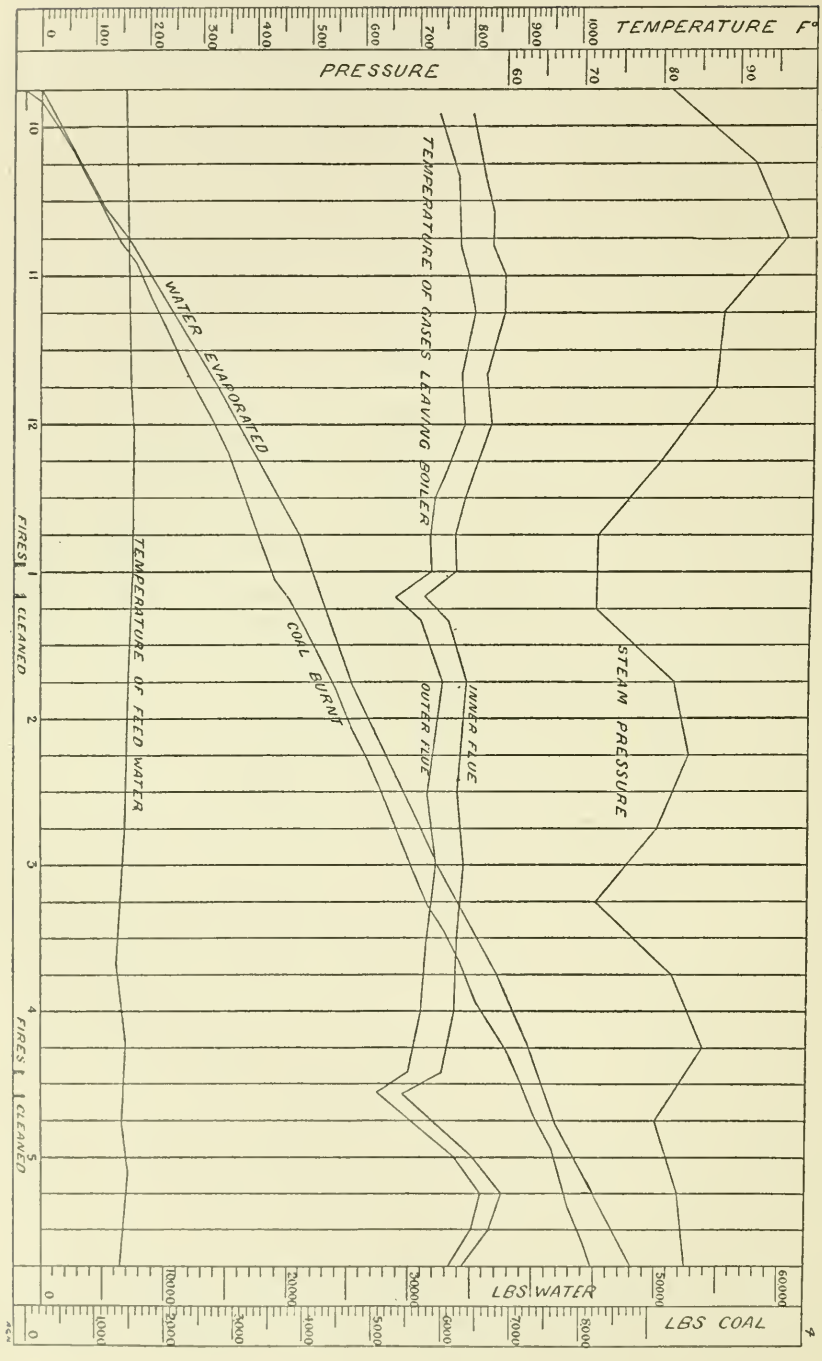
FIRES CLEANED
FIRES CLEANED
LBS WATER
LBS COAL


THURS. FEB 11 1904
TEMPERATURE
PRESSURE
TEMPERATURE OF GASES LEAVING BOILER
STEAM PRESSURE
WATER EVAPORATED
OUTER FLUE
INNER FLUE
COAL BURNT
TEMPERATURE OF FEED WATER
FIRES CLEANED
FIRES CLEANED
LBS WATER
LBS COAL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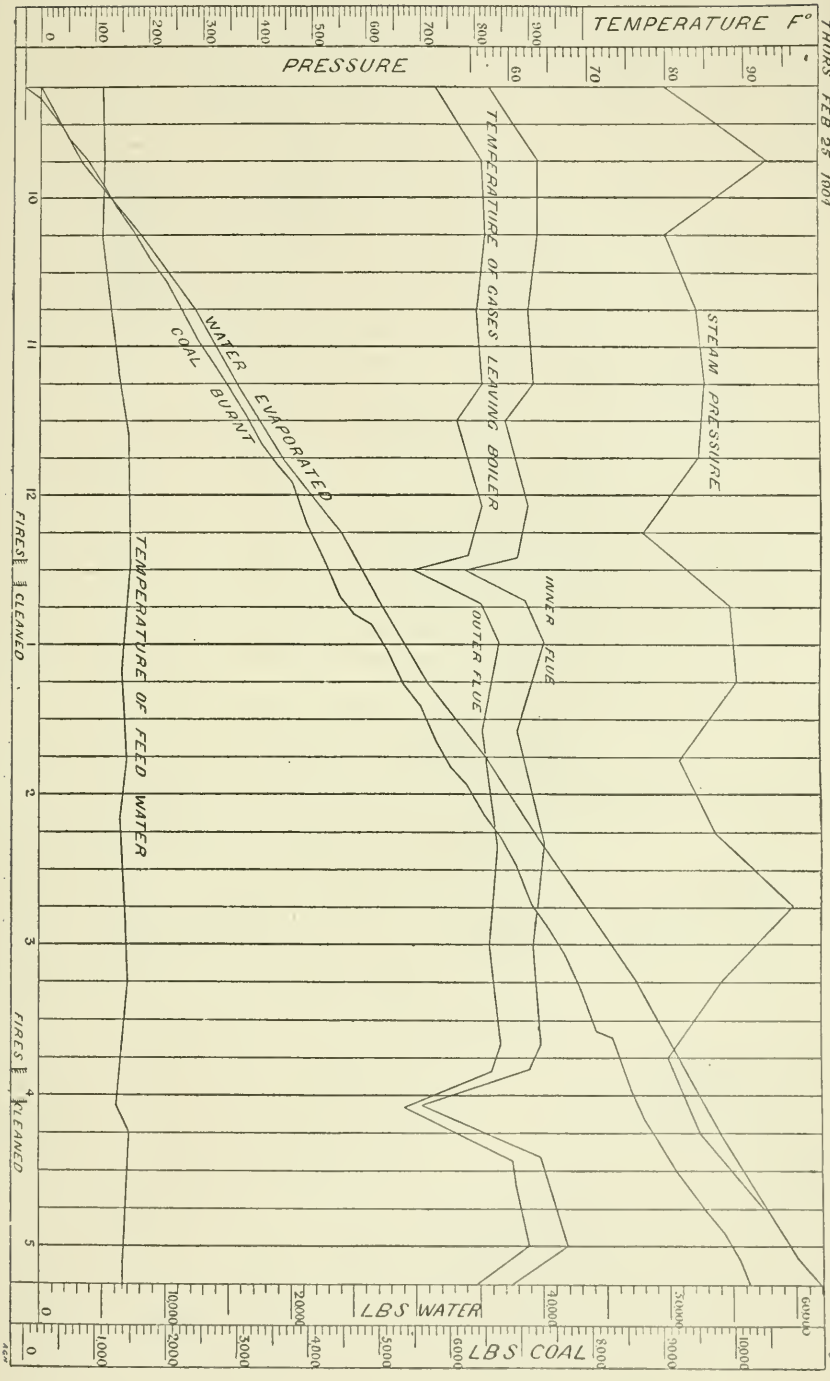
PRESSURE
TEMPERATURE OF GASES LEAVING BOILER
WATER EVAPORATED
COAL BURNT
TEMPERATURE OF FEED WATER
OUTER FLUE
INNER FLUE
STEAM PRESSURE
FIRES CLEANED
FIRES CLEANED
LBS WATER
LBS COAL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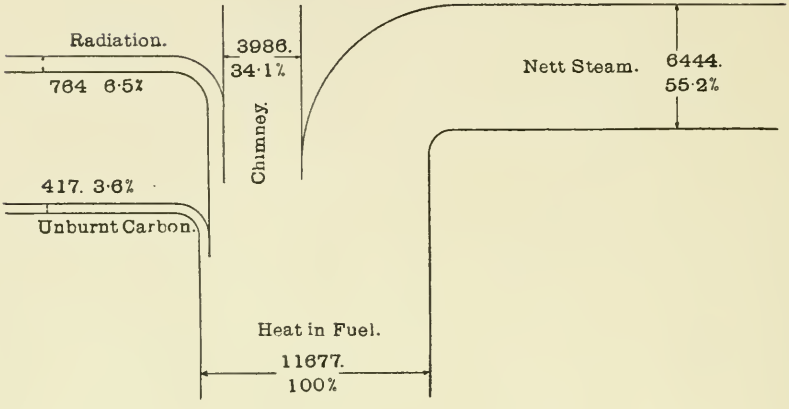
PRESSURE
THURS FEB 25 1904
TEMPERATURE OF GASES LEAVING BOILER
STEAM PRESSURE
WATER EVAPORATED
COAL BURNT
INNER FLUE
OUTER FLUE
TEMPERATURE OF FEED WATER
FIRES CLEANED
LBS WATER
LBS COAL

Haydock Colliery Trials.

9th February, 1903.



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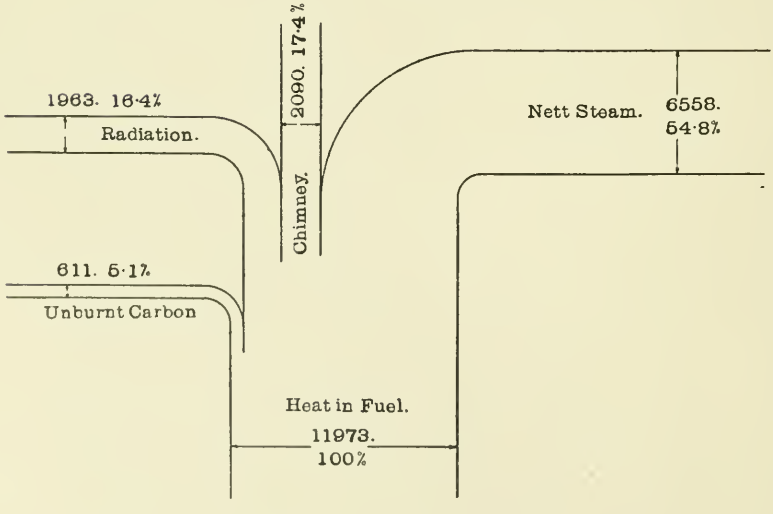
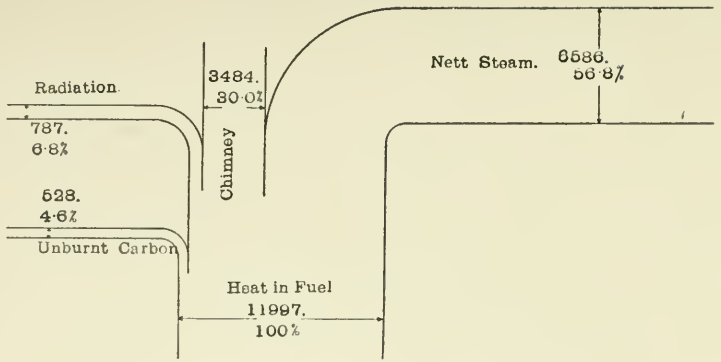
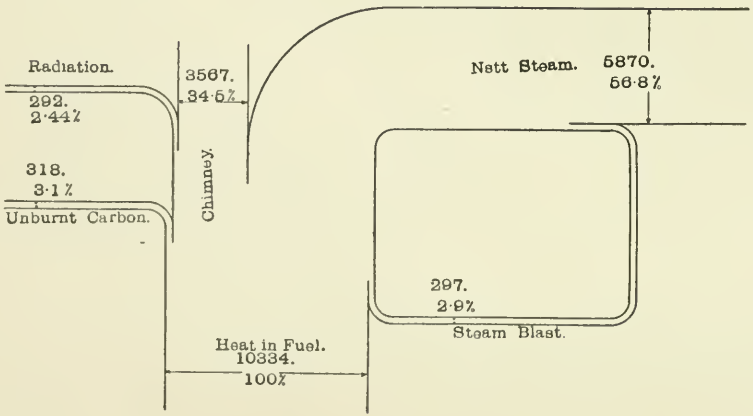


Haydock Colliery Trials.

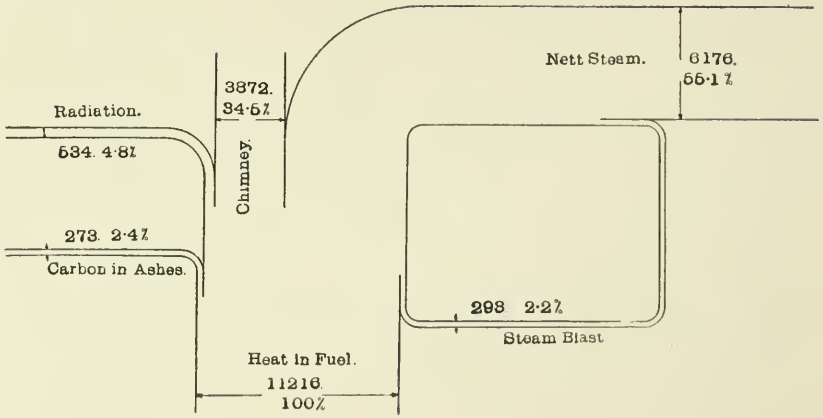
11th February, 1903.



24th February, 1903.



25th February, 1903.



On account of the difficulty of analysing gases for hydrocarbon, especially out of doors, as in this case, this was, unfortunately, not done, and there is a possibility that some unconsumed constituents were not detected in the waste gases; but the fact that the estimated hydrogen in the fuel was lower on February 10th than on any other day is a strong indication that some hydrogen had formed a hydrocarbon gas. A rough estimate shows that if the estimated hydrogen for that day had been equal to the average, about 500 B.Th.U. are at once accounted for, and then, taking the average calorific value, the item "radiation, &c.," would be reduced to 10·5 per cent., which is a much more probable value than that contained in the table; but then, of course, about 6 per cent. would have to be added to the item "incomplete combustion," making it about 12 per cent.

I am, Gentlemen,

Your obedient servant,

C. E. STROMEYER.

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This Association was the first institution to establish periodical boiler inspection on a practical basis.

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